An Economic Analysis of the Appalachian Coal Industry Ecosystem

County-level CIE Supply Chain Analysis

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Executive Summary

The continuing decline in the U.S. coal industry has implications that differ from industry to industry and from region to region. These differences in industry implications arise because of the nature of the coal industry ecosystem (CIE), in which each industry occupies its unique position in the coal industry supply chain. There are industries that provide goods and services directly to the coal industry, and those that supply the coal industry indirectly via provision of goods and services to the first-level suppliers and to their suppliers throughout subsequent supply chain levels and linkages. Likewise, each region has a unique mix of industries, so as collections of industries, regional economies also vary in terms of their position in the CIE, and in terms of the extent to which they are aligned with the coal industry. These critical differences, in turn, give rise to impacts of coal decline that can vary substantially from region to region, from state to state, and from county to county.

In this report, we describe an effort to provide for the Appalachian Region a clearer picture of the implications of long term declines in the coal industry, and the way in which these implications vary geographically. We develop and implement in this report three measures that reveal meaningful characteristics of the CIE at the county level, in terms of: industry and place-based CIE dependence, changes in CIE-dependent employment, and susceptibility to anticipated continued coal industry decline. We then combine these three measures—Dependence, Impact, and Risk—to form a typology that we apply to identify and focus on counties in three identifiable categories: Hardship counties, Vulnerable counties, and Depressed counties.

The 123 *Hardship* counties rank below the median of all counties on the Dependence and Risk dimensions, and above the median on the Impact dimension. These counties have experienced high levels of negative impacts, but because they have lost most of their CIE-dependent industry jobs, they are not at risk for further substantial coal decline-driven job loss. The 124 *Vulnerable* counties rank below the median score on the Impact dimension, but above median scores on the Dependence and Risk dimensions. These counties did not exhibit negative consequences of CIE decline between 2005 and 2015, but because they are CIE-dependent and at risk of further coal industry decline, they form a group of counties with higher potential for future coal decline-driven job loss. The 83 *Depressed* counties score above median on all three dimensions. They suffered CIE-dependent job losses between 2005 and 2015, they continue to host CIE-dependent industries, and they are at risk of further future coal decline job-loss.

Finally, we narrow focus on the Depressed counties that rank highest on all three CIE-dimensions. Specifically, there are nine Depressed counties that rank in the top 20 on all three CIE dimensions.

These are Mingo and Boone Counties in West Virginia; Harlan, Leslie, Martin, Pike, and Perry Counties in Kentucky; and Buchanan and Dickenson in Virginia. Unemployment rates in these counties range from a low of 8.9 percent to a high of 13.2 percent; job losses have been substantial, as high as 34 percent and averaging 21 percent. On average in these counties, roughly one in ten employees works in the coal industry itself, and their wages account for almost 23 percent of county totals. In two of these counties, coal-industry employment shares exceed 20 percent, and corresponding wage shares of total exceed 37 percent. These Depressed counties clearly warrant special attention and concern if current coal industry trends continue.

Introduction

To depict the production characteristics of the coal industry ecosystem requires an approach that recognizes the role of production supply chains. Like manufacturing activities, the coal mining industry relies on many other industries for the materials and supplies it consumes in the coal mining and production process. In turn, these industries also require inputs from other industries to produce the supplies used by the coal industry. These second-order suppliers require inputs from third-order suppliers, and so on. Together, these direct and indirect industry connections create a web of interindustry linkages that make up the coal industry's supply chain. This report uses industry-specific data and formal representations of interindustry linkages to assess Appalachian counties based on three primary dimensions of the coal industry ecosystem: Dependence, Impact, and Risk.

Overview

Given the declining trends in U.S. coal industry employment, we need a deeper understanding of the ways in which the implications of these declines vary regionally and which regions have been and might expect to be most strongly impacted by the downturn. There has been a growing focus on coal-impacted counties by federal agencies, in part due to direct funding and assistance programs for places that have been most heavily affected. Although coal-impacted county status generally carries a negative connotation, we also note that not all county CIEs have been negatively impacted. This leads us to define three important dimensions of CIEs: dependence, impact, and risk. Coal-dependence (hereafter simply Dependence) is defined by strong concentrations in industries that are central to the coal industry supply chain. Coal-impact (Impact) is defined by observed declines in coal-dependent industries. Noting the observed relationships between counties that have declined least and their coal mine productivity, we define a coal-risk (Risk) index by combining Region-wide and county-based coal-dependence and county-level coal mine productivity. Counties with high Dependence scores and low-productivity mines are at greatest risk of further negative impact and economic distress.

Analysis

To characterize counties relative to the CIE, we develop and implement a set of tools that target key supply chain industries and supply chain level impacts at the county level. Our methods use national benchmark input-output data from the U.S. Bureau of Economic Analysis, U.S. Department of Labor Mine Safety and Health Administration, U.S. Department of Commerce, Census of Population, and U.S. Bureau of Labor Statistics (BLS) Census of Employment and Wages (CEW).[1]

Each of the next three subsections describes one of the CIE dimensions used to characterize Appalachian counties, including conceptual underpinnings and discussions of results presented graphically and numerically in tabular format. Mathematical formulations for the three dimensions are included as appendices. Next, we present a typology of Appalachian counties derived by combining the information generated by the three separate dimensions. The typology's eight classes provide an effective summary of the extent to which Appalachian counties have been affected by coal industry declines.

CIE Dependence

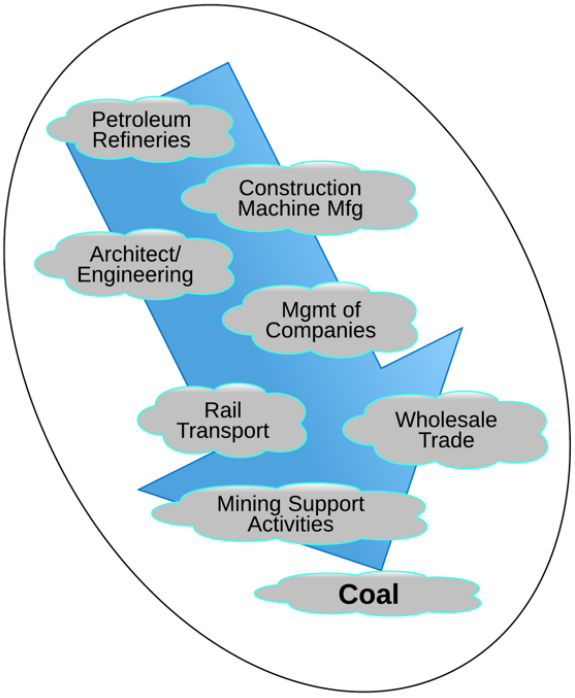
The overall objective in developing a county-based measure of coal dependence is to quantify the extent to which a county's economy is dependent on coal. Counties that have relatively large and diverse economies would be expected to be able to adapt to changes in the CIE better than those whose economic activities are tied strongly, either directly or indirectly, to the coal industry. In terms of economic resilience to coal industry downturns, then, Dependence is considered to be a negative.

CIE Industry Scores

To estimate county dependence on coal requires that we develop a way to measure each industry's direct and indirect dependence on coal. We can then combine this metric with county distributions of employment by industry to determine the shares of each industry's employment that are coal-oriented. The ratio of the sum of all industries' coal-oriented employment to county total employment will then provide a direct measure of county coal-dependence.

[1] The BLS data are enhanced and extended by the Implan Group, a well-established commercial provider of such data. Published BLS CEW data omit data values that are subject to disclosure rules. Implan provides consistent estimates for missing data at the county level.

Figure 1: Major Coal Industry Supply Chain Link



The first step in implementation is to define the CIE to include the coal mining industry and its supply chain-linked industries. Coal mining obviously occupies the central CIE position in the supply chain. Upstream supplier industries and downstream purchasers can be connected directly by sales to and purchases from the coal mining industry, or by supply chain links to suppliers and purchasers to their supply chain-linked industries, and so on, as shown in Figure 1. In this report, we focus our analyses on coal industry purchases (i.e., upstream, backward linkages) because the industries to which coal is sold are more likely to modify their inputs—e.g., substituting natural gas for coal—when coal production declines than they are to reduce their activity levels. Indeed, some production declines have resulted precisely *because* the downstream demand for coal production has declined. Therefore, the ties to the upstream industries are more easily identified and measured. Upstream industries' fortunes are tied more directly to the coal industry in that they are more likely to see demand for their products decline when coal production declines than are downstream industries.

Direct and indirect upstream purchase requirements all can be identified straightforwardly using technical requirements coefficients from benchmark input-output (IO) accounts. The national accounts identify the total input requirements, but not their geographical sources. Some supply chain transactions will be sourced within a county where coal mining occurs, some will be sourced elsewhere in Appalachia, and some will be outside of the Appalachian Region. We can estimate the extent to which industries in the Region are coal-oriented by comparing their output levels to the levels of supply

needed to satisfy the direct and indirect demand due to coal industry operation in the Appalachian Region. For these reasons, we use information from the U.S. Bureau of Economic Analysis national input-output accounts to define the technical relationships among industries and, in turn, use this technical information in combination with Appalachian coal production statistics to identify the shares of output from other industries that would be needed to support the Appalachian Region's coal industry. If an industry in the Appalachian Region produces less output than is needed to support Appalachian coal production, then we assume that all its production is entirely coal-dependent. If it produces more than enough to satisfy demands directly and indirectly associated with coal, then the coal-dependent share is the ratio of the amount needed by the Appalachian coal industry to the amount produced.

These industry shares, or CIE Scores, for the top industries in 2005 and 2015 are shown along with corresponding employment levels in Table 1, and all CIE Industry Scores are listed in Appendix I.[2] The value for the coal mining industry has the maximum value of 1.0 in both years indicating that all of its employment is coal-dependent, as would be expected. The other industries' shares lie between zero and 1.0, as only portions of their activity levels throughout the Region are dependent on coal. The industry-specific scores represent estimates of Dependence that reflect the ability of the entire Region to supply its own coal industry requirements. The scores imply that industries throughout the entire regional economy supply the entire Appalachian coal industry, irrespective of origin and destination of supply and demand, and that output from these industries goes first to the coal supply chain – the CIE – and then to other industries after all of the CIE demands have been met.[3] To provide more localized detail, parallel computations at the county level contribute to the Risk Score developed below.[4]

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[2] A few CIE Scores are quite large primarily because they correspond to industries with very low employment values. Consequently, these high scores will have minimal impact on county Dependence Scores.

[3] The formulation of these scores also implies frictionless transportation costs and no advantage for firms located near coal producing regions.

[4] Note that the BLS CEW data that we use for our calculations do not include reliable estimates for the Rail Transportation industry, so the score for this industry is omitted. No employees were reported in this CEW industry in 2005, and only 39 employees were reported for 2015, so, beyond the undercounting of Rail Transportation employees, there is no significant impact on any of the calculations in the report.

Table 1: Top Industry CIE Scores

Industry	2005 CIE Score	2005 Employment	2015 CIE Score	2015 Employment
Coal mining	1	47,140	1	36,535
Mining and oil and gas field machinery manufacturing	0.37	4,905	0.29	5,404
Primary smelting and refining of copper	0.04	149	0.16	19
Rubber and plastics hoses and belting manufacturing	0.24	2,191	0.13	1,890
Ground or treated mineral and earth manufacturing	0.15	483	0.1	595
Stone mining and quarrying	0.08	14,588	0.07	7,972
Commercial and industrial machinery and equipment rental and leasing	0.17	4,466	0.06	8,539
Oil and gas extraction	0.16	4,984	0.06	10,692
Water transportation	0.07	1,773	0.06	1,353
Construction machinery manufacturing	0.1	6,384	0.05	7,599

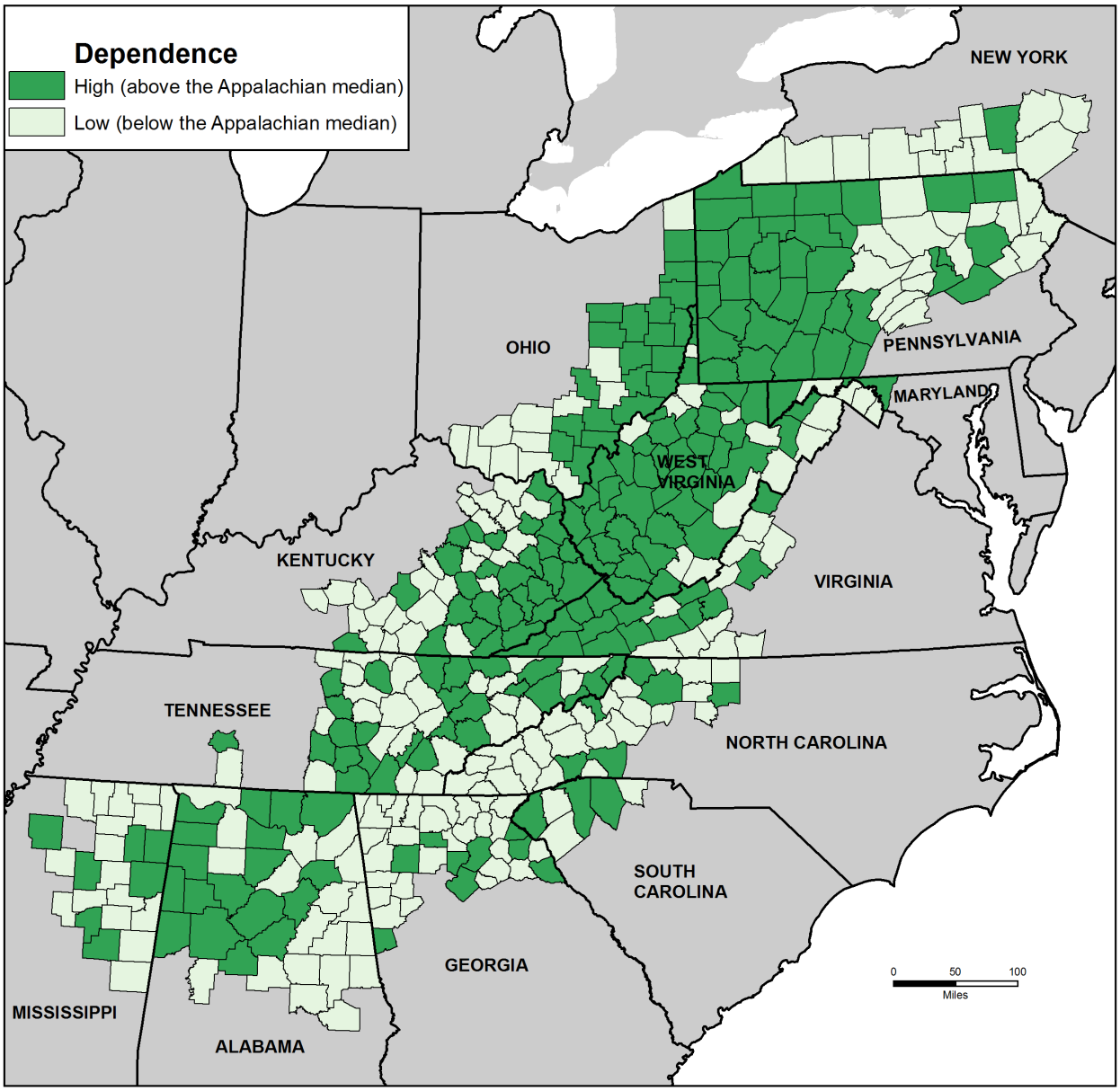
CIE County Dependence Scores

CIE Scores are then applied to county industrial employment levels to derive an estimate of the number of coal supply chain-oriented employees in each industry in each county. The sum of these coal-dependent county employees over all industries divided by total county employment is the Dependence Score for that county.

For an initial, broad-brush view of the distribution of Dependent Appalachian counties, Figures 2 and 3 present a two-way classification of counties, distinguishing those with greater scores than the median Dependence values from those with lower scores than the median. The maximum Dependence Score for 2005, expressed as a percentage, was 42.2 percent, but only a quarter of the counties had values greater than or equal to 1 percent, so the 2005 distribution is heavily skewed. By 2015, the maximum value had fallen to 22.4 percent, and less than one-fifth (73 counties, or 17.4 percent) of the counties in 2015 had values greater than 1 percent, resulting in a distribution of values that is even more strongly skewed. Between the two years, 76 of the 420 counties in the Appalachian Region (18.1 percent) shifted categories from low to high or *vice versa*, but none of those that switched are heavily coal-dependent.[5]

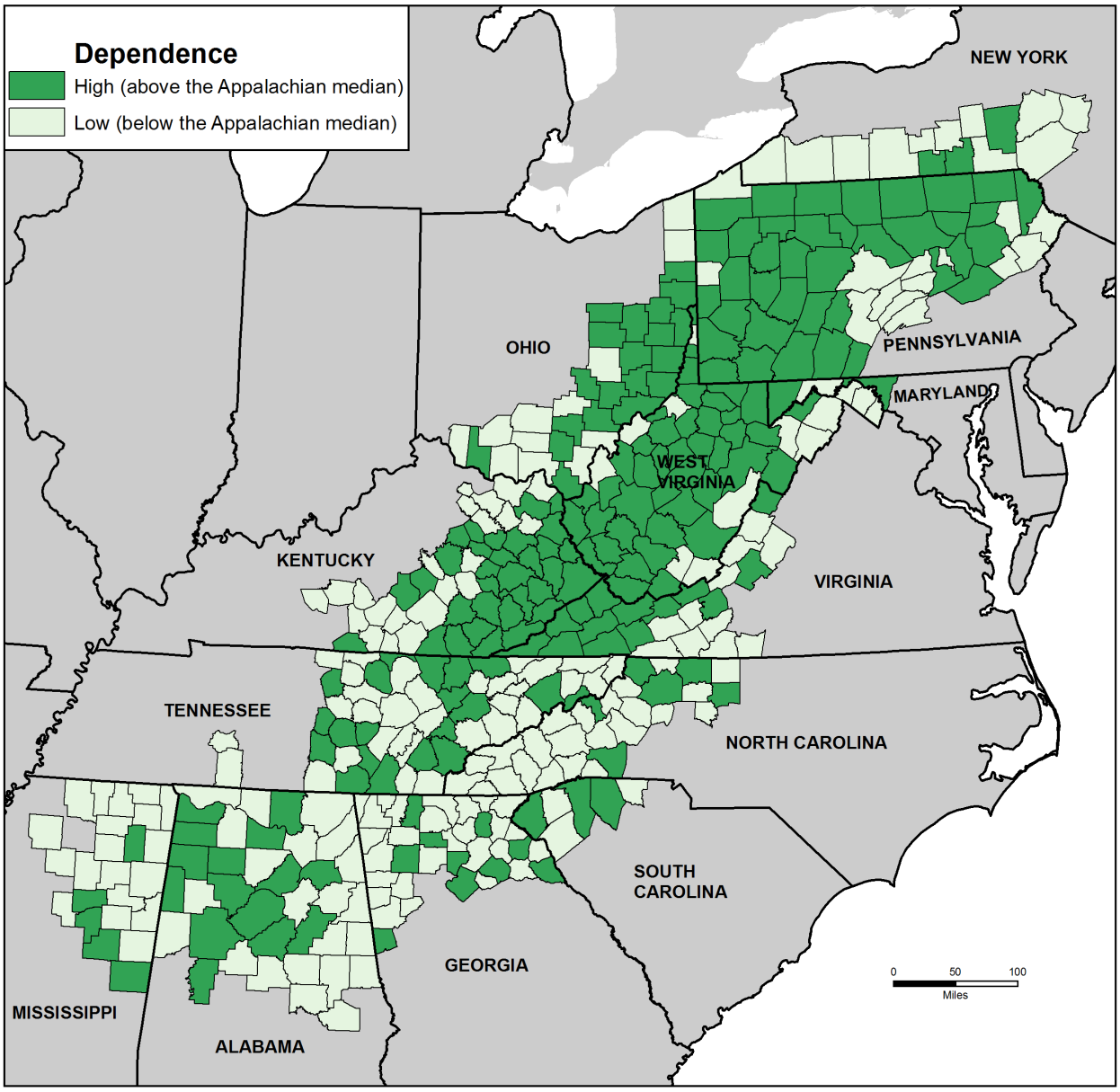
[5] Only eight of these counties had Dependence Scores greater than 1 percent in 2015.

Figure 2: Map of Coal-Dependent Counties, 2005



Data Sources: Bureau of Labor Statistics and Bureau of Economic Analysis

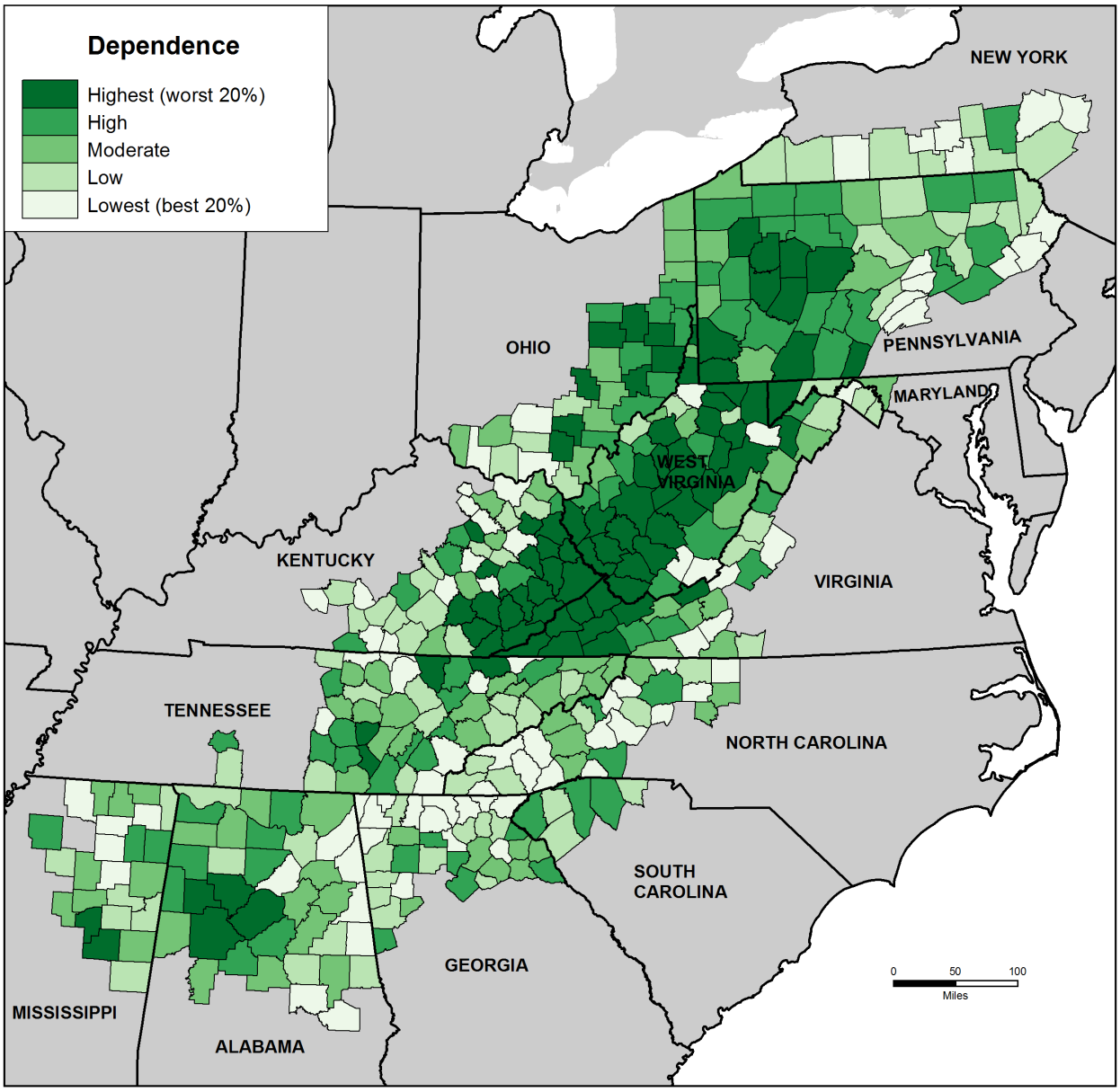
Figure 3: Map of Coal-Dependent Counties, 2015



Data Sources: Bureau of Labor Statistics and Bureau of Economic Analysis

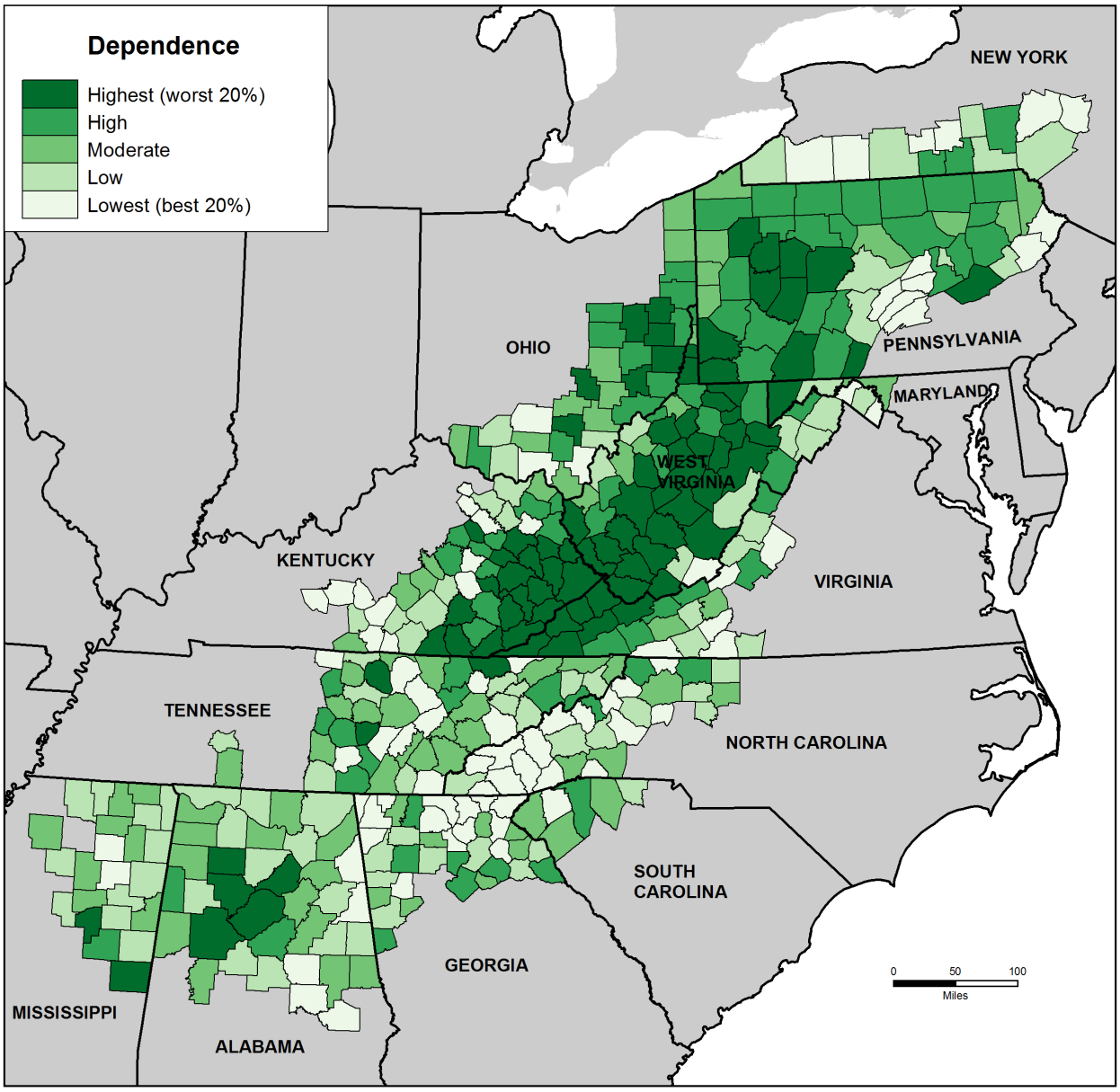
A more detailed view of Dependent counties is shown in Figures 4 and 5, which display county Dependence by quintile for 2005 and 2015. Bear in mind that there is far less variation in the lower four quintile intervals than in the highest quintile interval, and even within the highest quintile interval, the distribution remains skewed, where 73 of the 84 score values are less than half of the 22.4 percent maximum value, and ten of these counties have Dependence Scores with values less than 1 percent.

Figure 4: Map of Coal Dependence, 2005



Data Sources: Bureau of Labor Statistics and Bureau of Economic Analysis

Figure 5: Map of Coal Dependence, 2015



Data Sources: Bureau of Labor Statistics and Bureau of Economic Analysis

The complete listing of Dependence Scores by county appears in Appendix II. Table 2 below lists the counties that had the highest twenty scores in either 2005 or 2015, along with their corresponding scores and ranks in each year. The rank ordering of the counties shows some minor instability, but the composition of both lists is mostly the same. There are several ways in which Dependence Scores can change. Because it is a measure that is based on employed persons, not unemployed persons, county Dependence Scores can decline due to reductions in CIE employment *or* increases in non-CIE employment. Conversely, Dependence Scores can increase due to increases in CIE employment (which

is the explanation for the inclusion of the four new counties in the 2015 top 25 ranking) or decreases in non-CIE employment. Of course, offsetting changes can leave a county's Dependence Score unchanged.

Table 2: Highest CIE Dependence Counties, 2005 and 2015

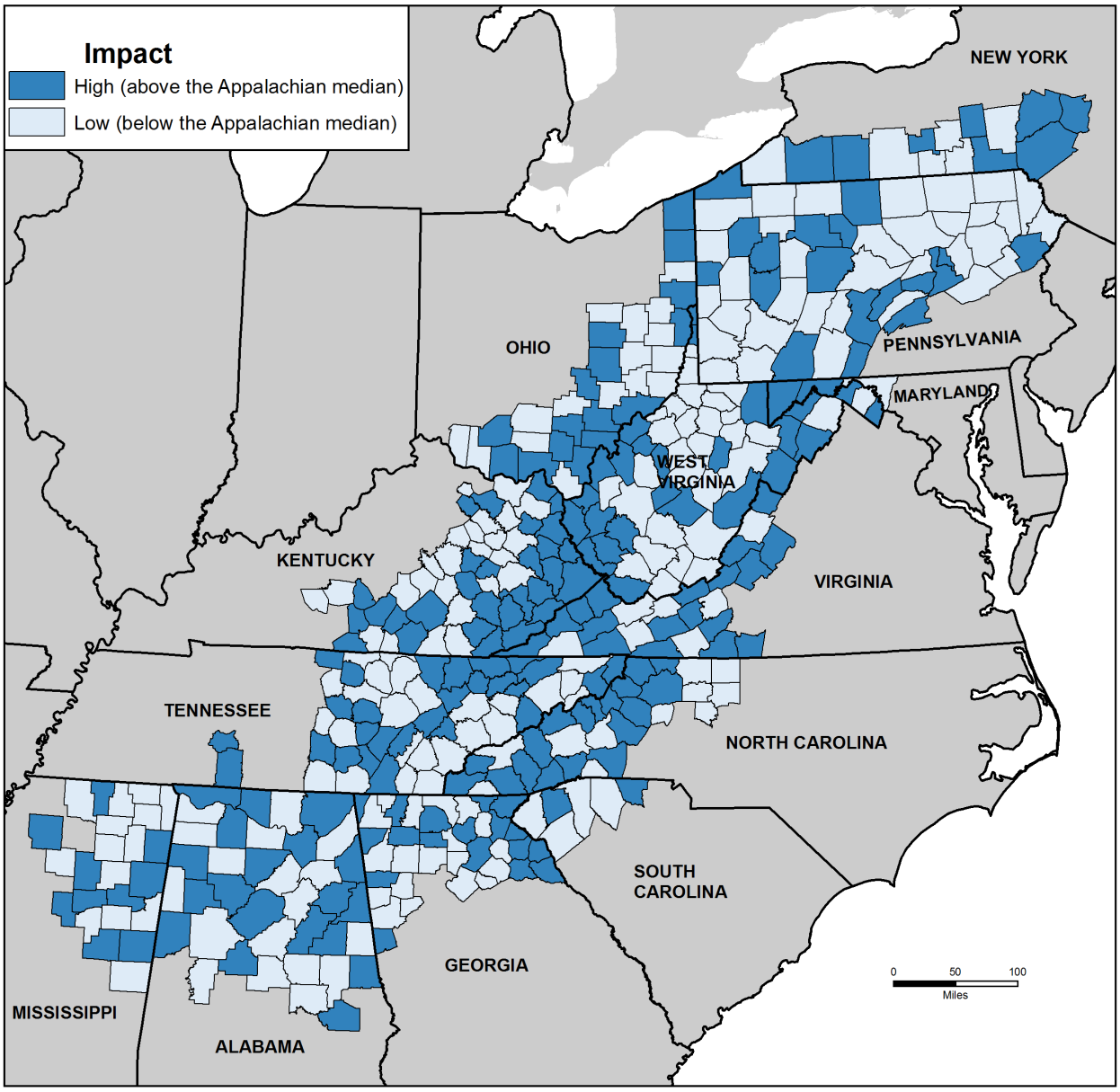
County Names	2005 Rank	2005 Dependence Score	2015 Rank	2015 Dependence Score
Boone County, West Virginia	1	42.2	3	21.9
Knott County, Kentucky	2	36.9	21	6.9
Leslie County, Kentucky	3	22.2	14	9.9
Mingo County, West Virginia	4	20.5	2	22.2
Greene County, Pennsylvania	5	19.8	4	18.4
Clay County, West Virginia	6	19.3	39	2.7
Martin County, Kentucky	7	18.3	11	11.9
Buchanan County, Virginia	8	17.1	6	15.3
Letcher County, Kentucky	9	16.4	23	5.6
Dickenson County, Virginia	10	16.3	9	12
Wyoming County, West Virginia	11	15.9	1	22.4
McDowell County, West Virginia	12	15.8	7	14.8
Pike County, Kentucky	13	15.8	18	8.6
Harlan County, Kentucky	14	14.9	15	9.8
Marshall County, West Virginia	15	12.2	5	17.3
Perry County, Kentucky	16	11.8	13	10.3
Logan County, West Virginia	17	11.6	12	11.6
Choctaw County, Mississippi	18	10.5	10	11.9
Webster County, West Virginia	19	9.6	8	13.3
Bell County, Kentucky	20	9	24	5.1
Harrison County, Ohio	22	8.9	16	8.9
Marion County, West Virginia	24	6.8	17	8.7
Taylor County, West Virginia	333	0.4	20	7.6
Tucker County, West Virginia	364	0.3	19	7.8

CIE Impact

Our county-level CIE Impact Scores are formed by combining the industry-based CIE Scores with employment *change* by industry, expressing the sum of the employment change-weighted CIE Scores as a share of total employment. The rationale for this approach is that if observed job loss occurs in coal-oriented industries, then this negative economic impact and accompanying economic distress is the share of that employment loss that is associated with the coal industry. Employment change is defined as 2015 employment less 2005 employment.[6] Employment loss yields negative values, so larger negative values correspond to greater negative Impact. Perhaps somewhat surprisingly, roughly 40 percent of counties actually *gained* in CIE related employment, which supports the observation that reliance on coal has not been uniformly negative across Appalachia. In 150 Appalachian counties, the Impact Score was between 0 percent and 1 percent, indicating relatively insubstantial change in CIE employment. Another 15 counties had Impact Scores between 1 percent and 3 percent, and the remaining positive Impact Scores fell between 3 percent and 8 percent. Of the counties in the High Negative Impact and Moderate Negative Impact categories, the largest value is 32.797. All but three of the 84 counties in the Low Impact category have negative values greater between -0.059 and -0.006, and the three positive values are less than 0.002. The Moderate Positive Impact category values range from 0.002 to 0.112, and the remainder range upward to 7.733. All Impact Scores are included in Appendix I. Figures 6 and 7 show Appalachian county Impact in two-category and quintile representation formats, paralleling the Dependence figures above.

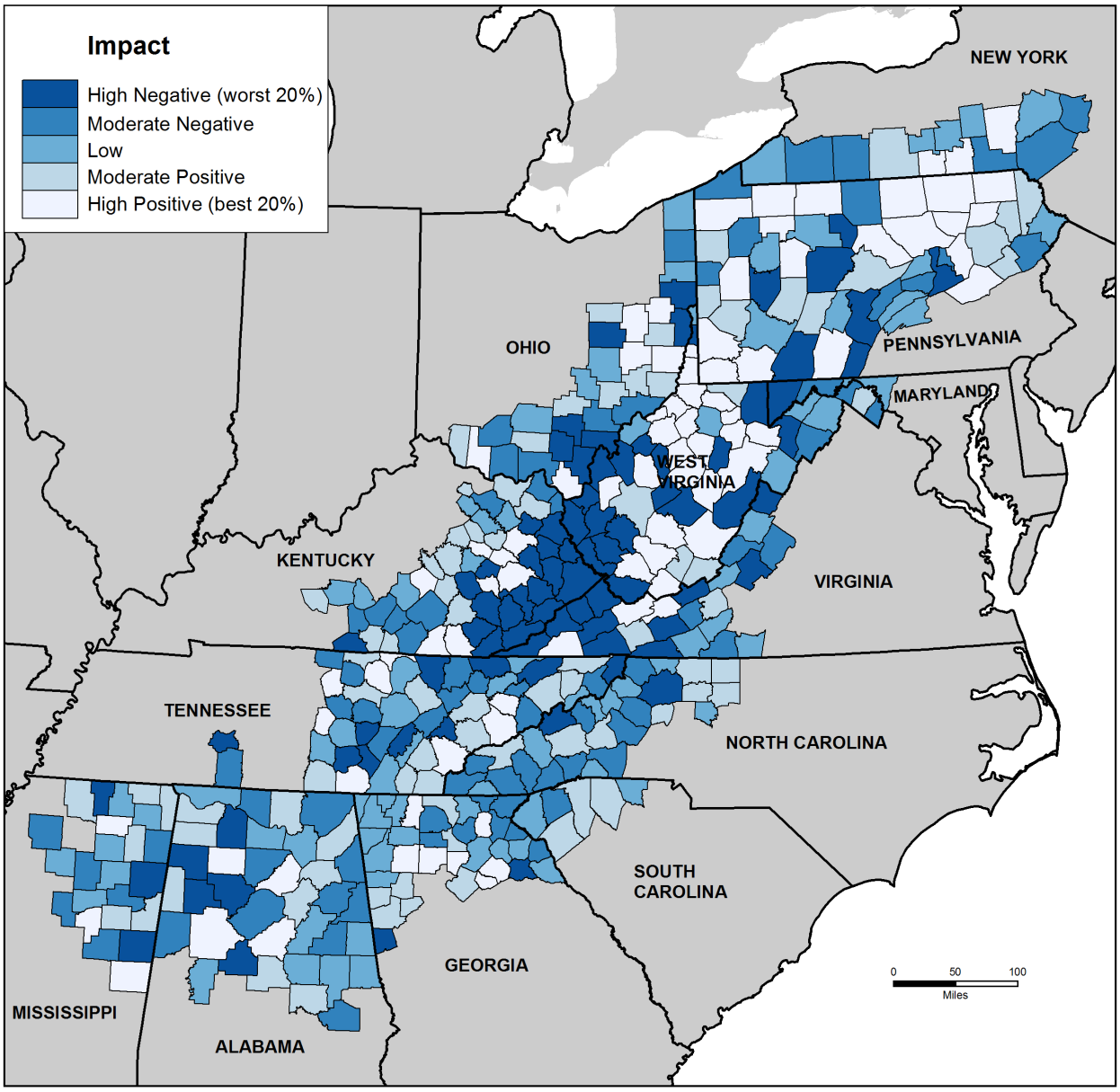
[6] Of course, employment in CIE industries could be changing for other reasons, but the implied assumption of causality is used because of a lack of mechanism by which to identify other causes.

Figure 6: Map of CIE Impacted Counties



Data Sources: Bureau of Labor Statistics and Bureau of Economic Analysis

Figure 7: Map of CIE Impact by Quintile



Data Sources: Bureau of Labor Statistics and Bureau of Economic Analysis

Counties with the highest Impact Scores are shown in Table 3. Thirteen of the 20 most impacted counties appear in the list of most Dependent counties in Table 2. These thirteen county names appear in bold in Table 3.

Table 3: Highest CIE Impact Counties

Rank	County Names	Impact Score
1	**Knott County, Kentucky**	-32.8
2	**Boone County, West Virginia**	-27.6
3	**Clay County, West Virginia**	-17.4
4	**Leslie County, Kentucky**	-14.8
5	**Letcher County, Kentucky**	-12.4
6	**Martin County, Kentucky**	-8.6
7	**Pike County, Kentucky**	-8.1
8	**Harlan County, Kentucky**	-7.7
9	Fayette County, Alabama	-6.7
10	**Mingo County, West Virginia**	-5.5
11	Wise County, Virginia	-5.5
12	**Bell County, Kentucky**	-4.7
13	Grant County, West Virginia	-4.4
14	Vinton County, Ohio	-4.3
15	**Buchanan County, Virginia**	-3.5
16	**Dickenson County, Virginia**	-2.9
17	**Perry County, Kentucky**	-2.6
18	Clay County, Kentucky	-2.4
19	Nicholas County, West Virginia	-2.3
20	Elliott County, Kentucky	-2.3

Note: Bold counties also appear on list of Dependent counties

CIE Risk

Our objective for this third dimension of CIE counties is to quantify the degree to which Appalachian Region counties are at risk of experiencing additional economic hardship should the decline in the coal industry continue. We base our conceptual framework for risk on the observation that counties with the largest observed CIE declines are generally those with low coal-mine productivity. Consistent with established economic principles, the lowest productivity mines will be least profitable and, therefore, at greatest risk of closure. Highly productive mines will be most profitable and are, thus, at lowest risk for closure even in the face of overall industry decline.[7] Counties that have no mines but that do have employment concentrations in CIE industries are at risk via supply chain linkages. This overall risk is directly correlated with the Dependence Scores. Counties that are host to operating mines face direct

[7] There are, of course, other reasons why mine can be uncompetitive, such as poor management practices, but these factors lie beyond our ability to measure.

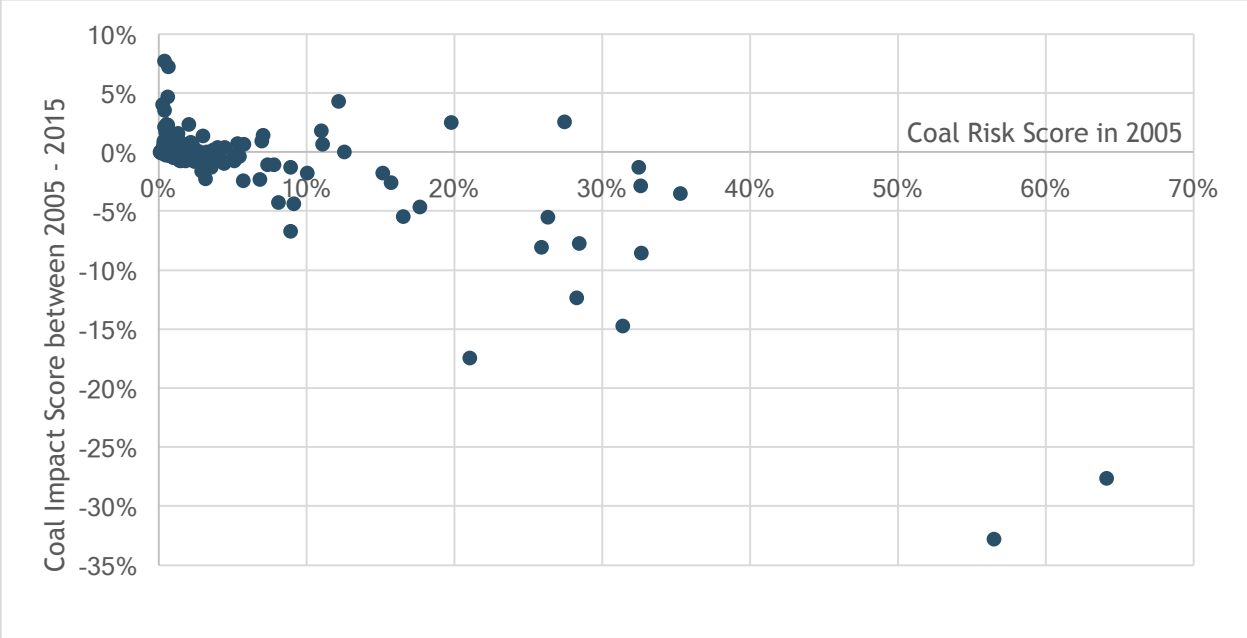
risks of declining coal industry operation and localized supply-chain linkages that are tied to localized coal industry support activity. To capture this additional level of localized risk in coal-producing counties, we compute county-specific CIE industry scores from localized rather than Region-wide production levels, and we then use these localized scores to generate a localized dependence score for each county.

Mine productivity is assigned an index value between 0.0 and 1.0, and the localized dependence score values can vary from 0.0 to 1.0. The final Risk Score is the original, Region-wide Dependence Score combined with these two new variables. The formula for doing so is $CRS = (CDS)(1 + Q)(1 + B)$, where *CRS* and *CDS* are CIE Risk and Dependence Scores, *Q* is the county-specific productivity-based risk index, and *B* is the localized, county-specific dependence score. More formal mathematical expressions for all measures are included in Appendix III.

Correlation between Risk Score and Coal Impact

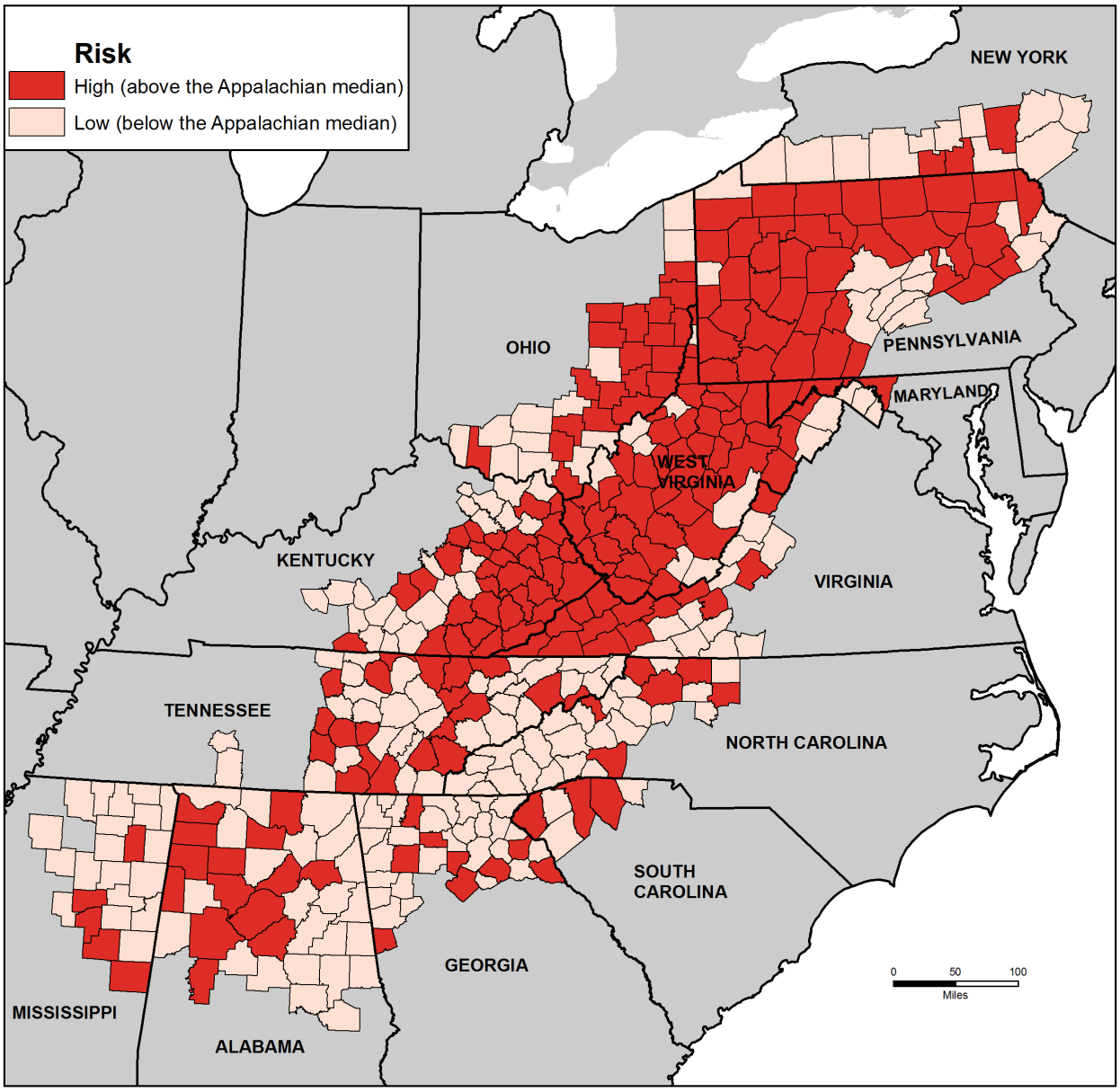
To confirm the validity of the Risk Score formulation and its interpretation, we calculated the 2005 CIE Risk Scores and compared them to the CIE Impact Scores. If our representation of Risk is well formulated, we should expect high-risk counties in 2005 to experience high negative impacts over the 2005-2015 period, hence a negative correlation between the two variables across counties. Our expectations were confirmed by a correlation coefficient of -0.78. This suggests that most, but not all, high-risk counties indeed experienced negative impacts. There are some exceptions, of course, but an examination of the plot of this relationship in Figure 8 reveals that even in the absence of the extreme values on both scales, the generally negative relationship is readily apparent. This result confirms that counties with high 2015 CIE Risk warrant special attention and concern should the declining coal industry trends continue.

Figure 8: Correlation (-0.779) between Coal Risk Score and Coal Impact Score



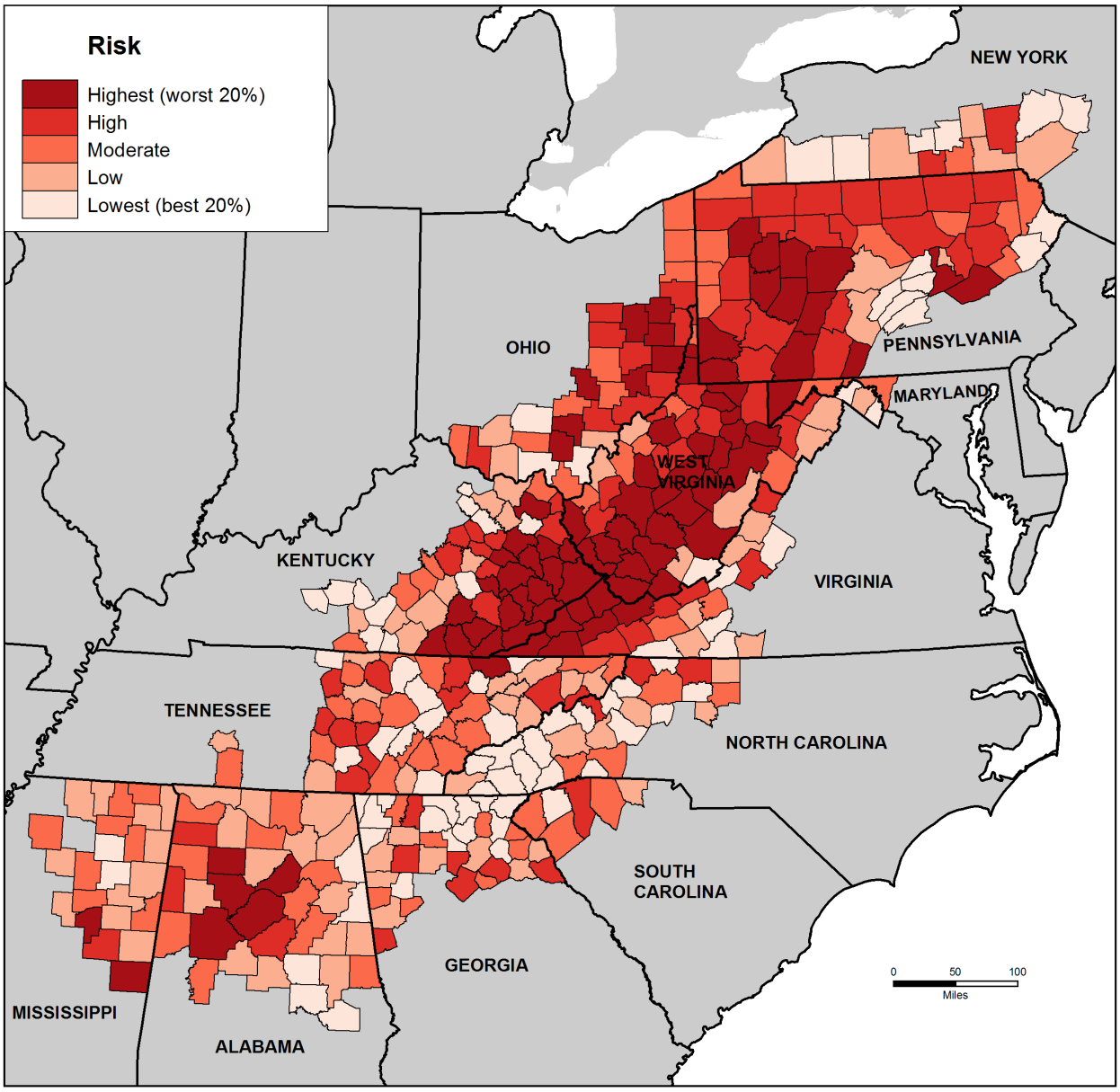
Consistent with Dependence and Impact presentations above, Figure 9 displays the broad-brush view of Risk by county, and Figure 10 displays Risk Scores by quintile. Since the objective is to identify counties still at risk of economic hardship from future coal decline, the only the Risk measure based on 2015 data is used for the CIE analysis.

Figure 9: Map of 2015 CIE Risk



Data Sources: Bureau of Labor Statistics, Bureau of Economic Analysis and Mine Safety and Health Administration

Figure 10: Map of 2015 CIE Risk Score by Quintile



Data Sources: Bureau of Labor Statistics, Bureau of Economic Analysis and Mine Safety and Health Administration

Ten of the 20 most impacted counties appear in the lists in Tables 2 and 3. These ten county names appear in bold in Table 4. Because Dependence is a component of Risk, these two measures are more strongly correlated than other CIE-dimension pairs.

Table 4: Highest CIE Risk Counties and Associated Values

Rank	County Names	Region-wide Dependence	Localized Dependence	Mine-Productivity Risk	Risk Score
1	Wyoming County, West Virginia	22.4	7.1	77.4	42.5
2	**Boone County, West Virginia**	21.9	6.5	64.6	38.4
3	**Mingo County, West Virginia**	22.2	5.8	50.3	35.3
4	McDowell County, West Virginia	14.8	3.2	97.6	30.2
5	**Buchanan County, Virginia**	15.3	4.5	46.3	23.4
6	Webster County, West Virginia	13.3	2.9	69.7	23.2
7	**Martin County, Kentucky**	11.9	3	87.5	22.9
8	**Dickenson County, Virginia**	12	3.3	78.2	22.1
9	Greene County, Pennsylvania	18.4	0	0	18.4
10	Logan County, West Virginia	11.6	3.5	53	18.3
11	**Harlan County, Kentucky**	9.8	2.6	75.2	17.7
12	Marshall County, West Virginia	17.3	0	0	17.3
13	**Pike County, Kentucky**	8.6	2.9	77.2	15.7
14	**Leslie County, Kentucky**	9.9	2	52.9	15.5
15	**Perry County, Kentucky**	10.3	2.6	40	14.8
16	Choctaw County, Mississippi	11.9	0.4	5.6	12.6
17	Harrison County, Ohio	8.9	1.7	30.2	11.7
18	**Letcher County, Kentucky**	5.6	1.5	91.6	10.9
19	Raleigh County, West Virginia	5.8	2.1	82.4	10.9
20	Taylor County, West Virginia	7.6	1.1	31.3	10.1

Note: Bold counties also appear in the list of most Dependent and Impacted counties.

CIE County Typology

To combine the information from the three dimensions and create a more comprehensive perspective on the Appalachian Region CIE, we developed a typology using an eight-way classification scheme. We assign counties to classes using combinations of the three High–Low groups on each dimension. Counties in Class 1 have High scores on all dimensions, counties in Class 8 have Low scores on all dimensions, and those in Classes 2–7 have varying combinations of High and Low category scores on the

three dimensions. The resulting typology is depicted graphically in figure 11 and in tabular form in Table 5, along with the number of counties in each Class.

Figure 11: CIE County Typology

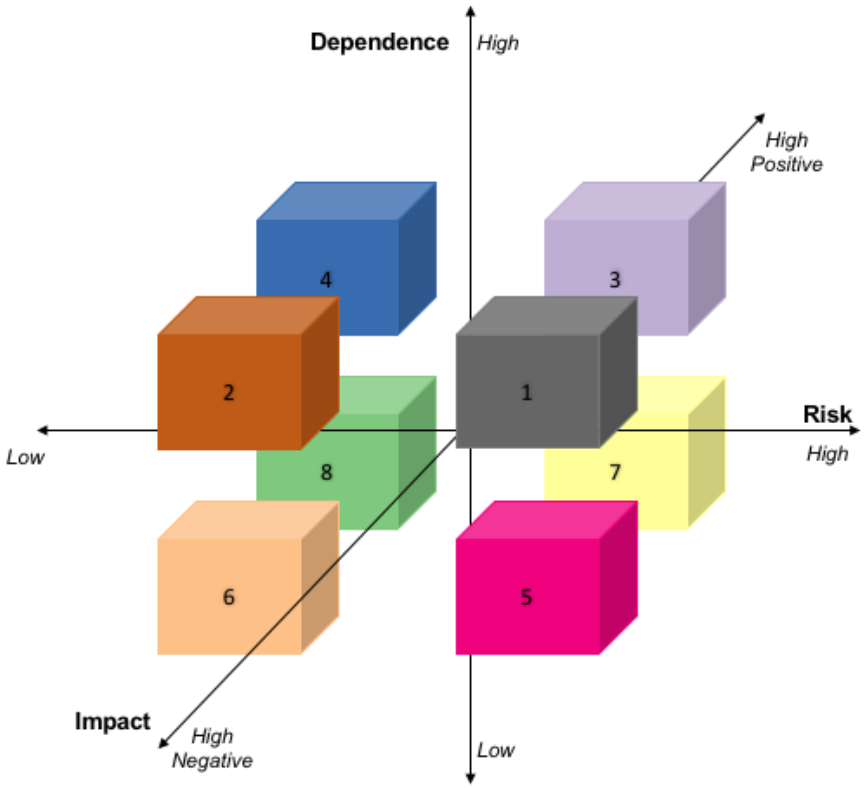


Table 5: Typology Score Combinations

Class	Dependence	Impact	Risk	Counties in Class
1	High	High	High	83
2	High	High	Low	2
3	High	Low	High	124
4	Low	High	High	2
5	High	Low	Low	1
6	Low	High	Low	123
7	Low	Low	High	1
8	Low	Low	Low	84

Counties in Classes 1 through 8 can be seen in the panels of Maps 9 and 10, and the overall distribution of counties by Class is shown in Map 11. Classes 1, 3, 6, and 8 are the most heavily populated, as would be expected given the correlation between Dependence and Risk. Counties in Class 1 are clearly the most distressed, and comprise the Depressed category. Counties in Class 3, the Vulnerable counties, have not yet faced the levels of economic hardship of other CIE-dependent counties but are vulnerable to continued coal-industry decline. The Class 6 Hardship counties have experienced CIE-based declines, but because they have lost the majority of their CIE, their economies are no longer CIE-dependent, so are not expected to incur further substantial CIE-based job loss. Counties in Class 8 are the least affected by the coal industry.

Figure 12: Maps of CIE Typology, Classes 1 through 4

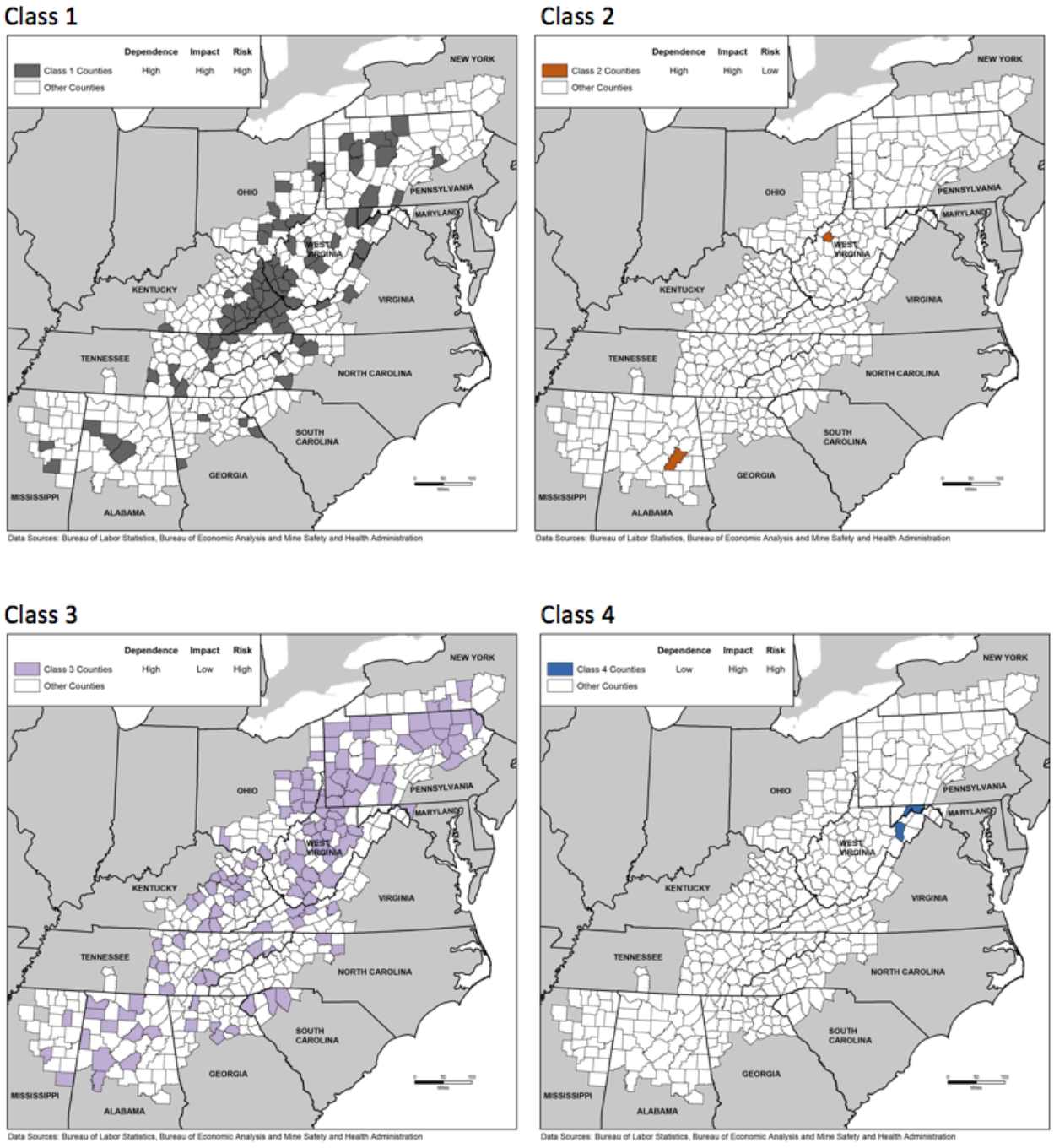


Figure 13: Maps of CIE Typology, Classes 5 through 8

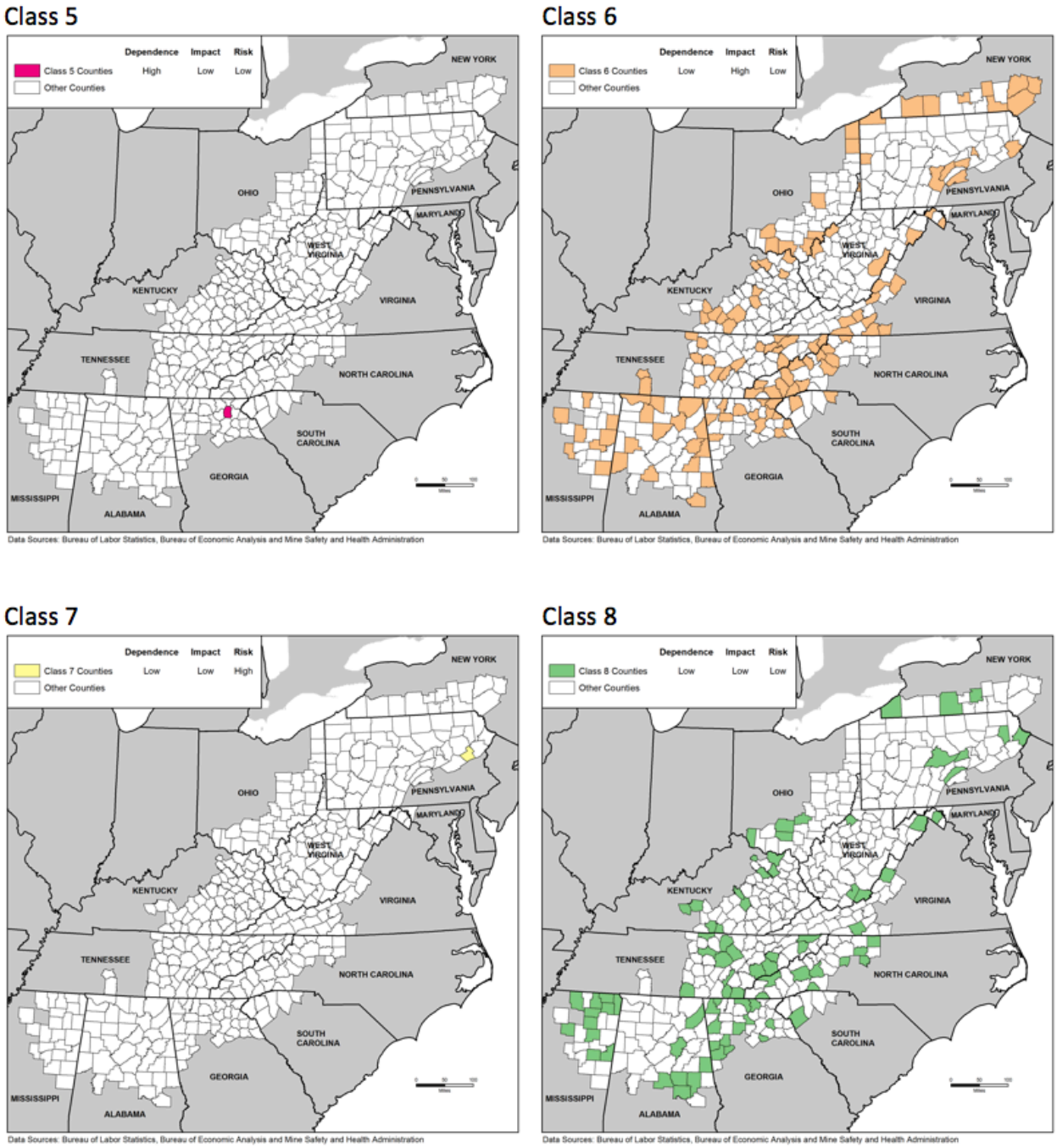
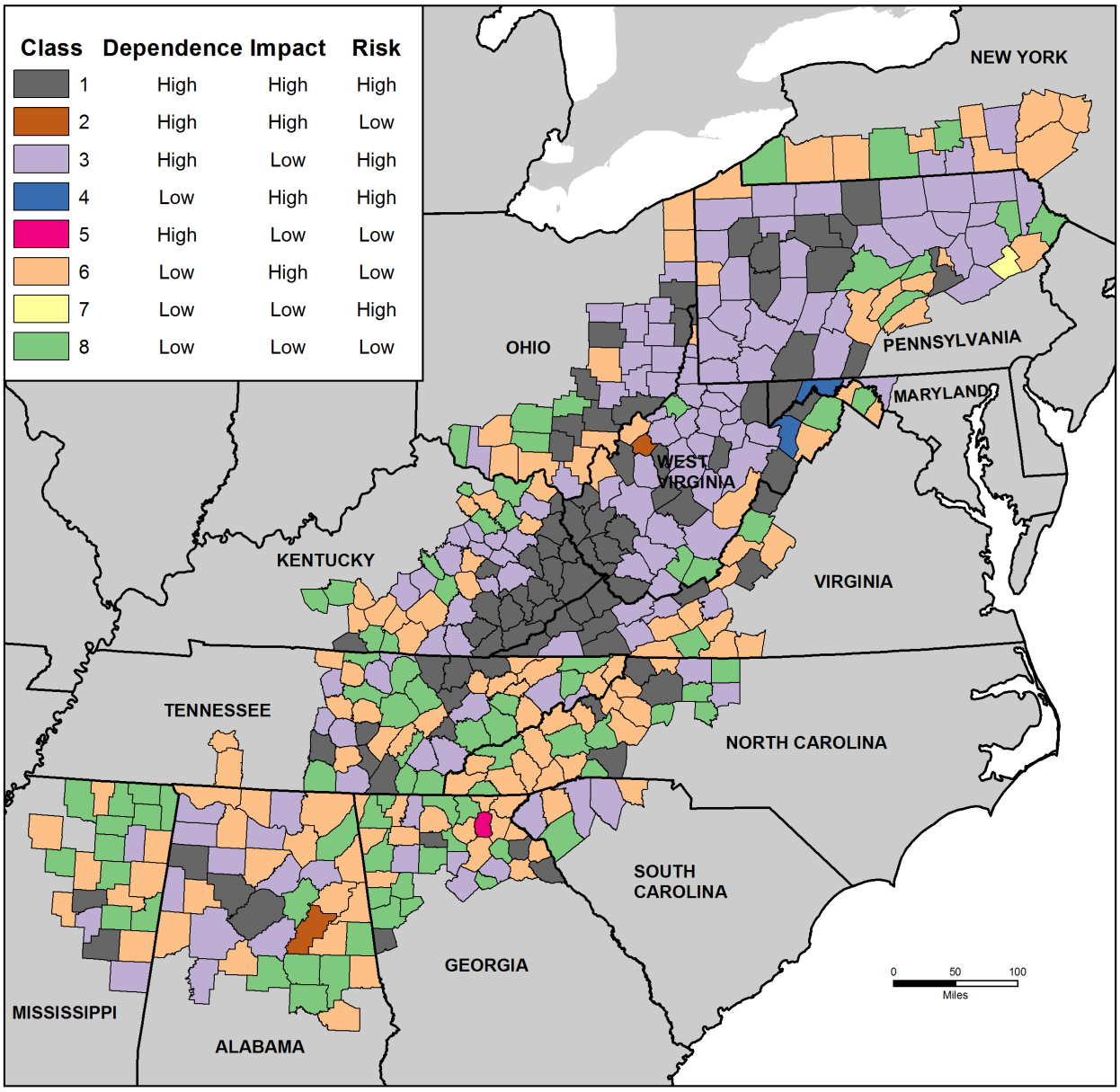


Figure 14: Map of CIE Typology, all Classes



Data Sources: Bureau of Labor Statistics, Bureau of Economic Analysis and Mine Safety and Health Administration

Three spatial patterns are most evident from these maps. First, the Class 1 Depressed counties are most heavily clustered near the West Virginia, Kentucky, and Virginia border intersections. Second, the Class 6 Hardship counties tend to be located near the periphery of the Region. Third, while the Class 3 Vulnerable counties are relatively widely dispersed in the Region's southern states, they dominate West Virginia and Pennsylvania counties in the Region. There is also a cluster of nine contiguous Class 3 counties in eastern Ohio.

Coal-Distressed Counties

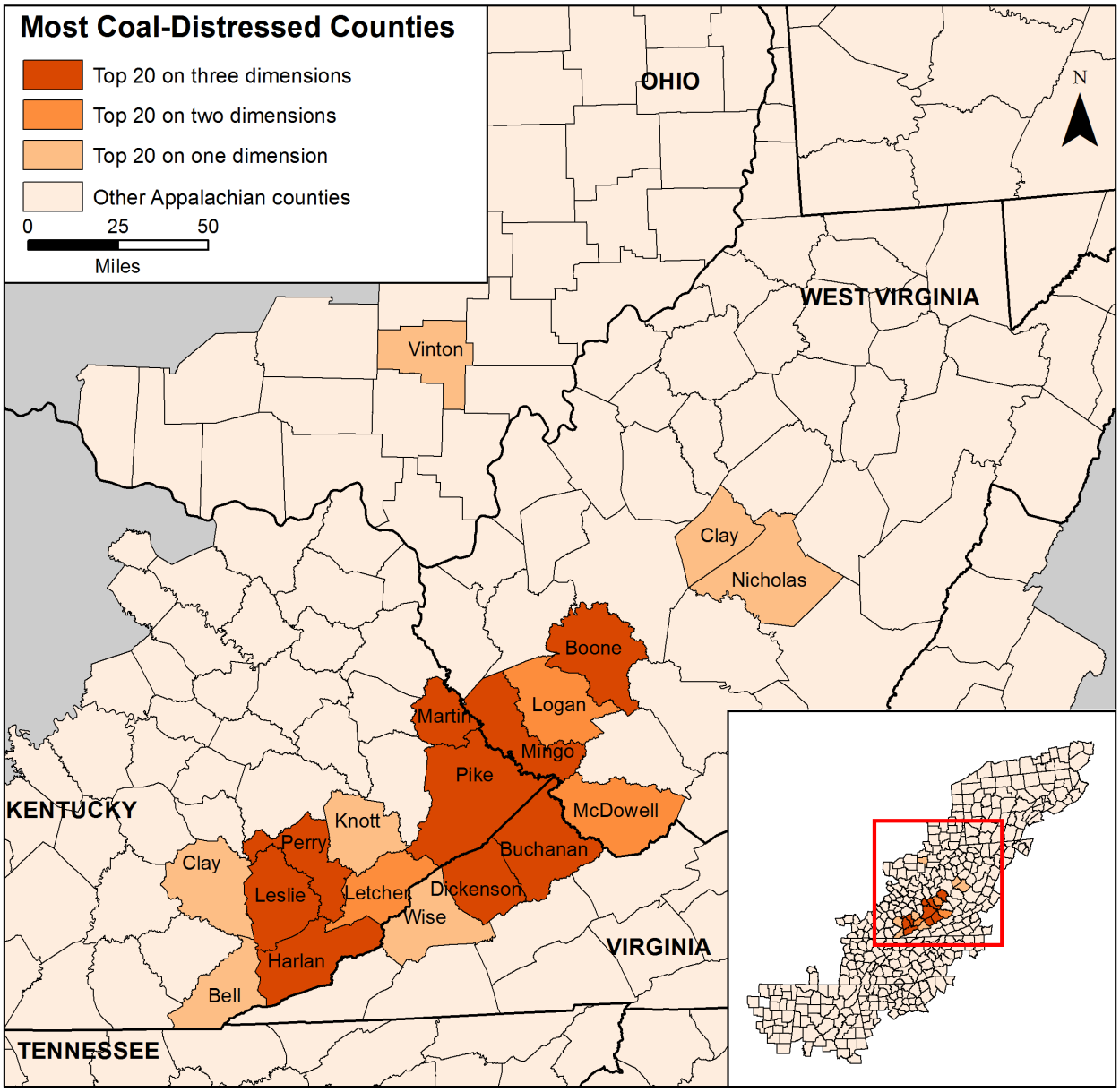
This section focuses on counties in Class 1 whose scores on all dimensions distinguish them from the others. We identify two sets of such counties. The first set is composed of those counties within Class 1 that also hold a top-20 ranking in at least one of the three CIE dimensions. This first set is shown in Table 6, along with their dimension-rankings and key socioeconomic variables. The group of counties shaded dark blue have no ranking lower than 20 on any of the CIE dimensions. The group in light blue has only one ranking lower than the top-20 ranking, and the third group has only one top-20 ranking. As can be seen in Figure 15, these counties are clustered in the heart of the Appalachian Region, with Vinton County, Ohio, as the only county located outside of West Virginia, Virginia, and Kentucky.

Table 6: CIE Class 1 Counties with One or More Top-20 Rankings

County	2015 Dependence Rank	Impact Rank	2015 Risk Rank	Unemploy-ment Rate %	Population	Per capita personal income $
Mingo County, West Virginia	2	10	3	13.2	25,292	29,416
Harlan County, Kentucky	15	8	11	11.9	27,703	27,920
Leslie County, Kentucky	14	4	14	10.9	10,711	30,047
Buchanan County, Virginia	6	15	5	10.9	22,776	32,032
Dickenson County, Virginia	9	16	8	10.1	15,115	28,443
Boone County, West Virginia	3	2	2	9.7	23,372	31,352
Martin County, Kentucky	11	6	7	9.6	12,307	27,056
Pike County, Kentucky	18	7	13	9.3	61,792	33,354
Perry County, Kentucky	13	17	15	8.9	27,565	35,148
McDowell County, West Virginia	7	25	4	12.8	19,835	27,107
Letcher County, Kentucky	23	5	18	11.2	23,123	30,562
Logan County, West Virginia	12	22	10	11.2	34,707	33,546
Wise County, Virginia	31	11	27	12.6	43,657	29,829
Clay County, West Virginia	39	3	42	11.2	8,910	29,045
Knott County, Kentucky	21	1	24	10	15,693	28,652
Clay County, Kentucky	108	18	94	9.5	21,013	26,608
Nicholas County, West Virginia	34	19	31	9.1	25,594	32,184
Bell County, Kentucky	24	12	22	8.5	27,337	29,042
Vinton County, Ohio	66	14	60	6.5	13,048	30,478

Note: Bold counties are "Distressed" and those in italics are "At-Risk" counties in the 2017 Appalachian Regional Commission classifications. The appearance of Vinton County, Ohio in this table is largely due to the presence of a single large employer that provides services to the mining industry.

Figure 15: CIE Class 1 Counties with One or More Top-20 Rankings



Data Sources: Bureau of Labor Statistics, Bureau of Economic Analysis and Mine Safety and Health Administration

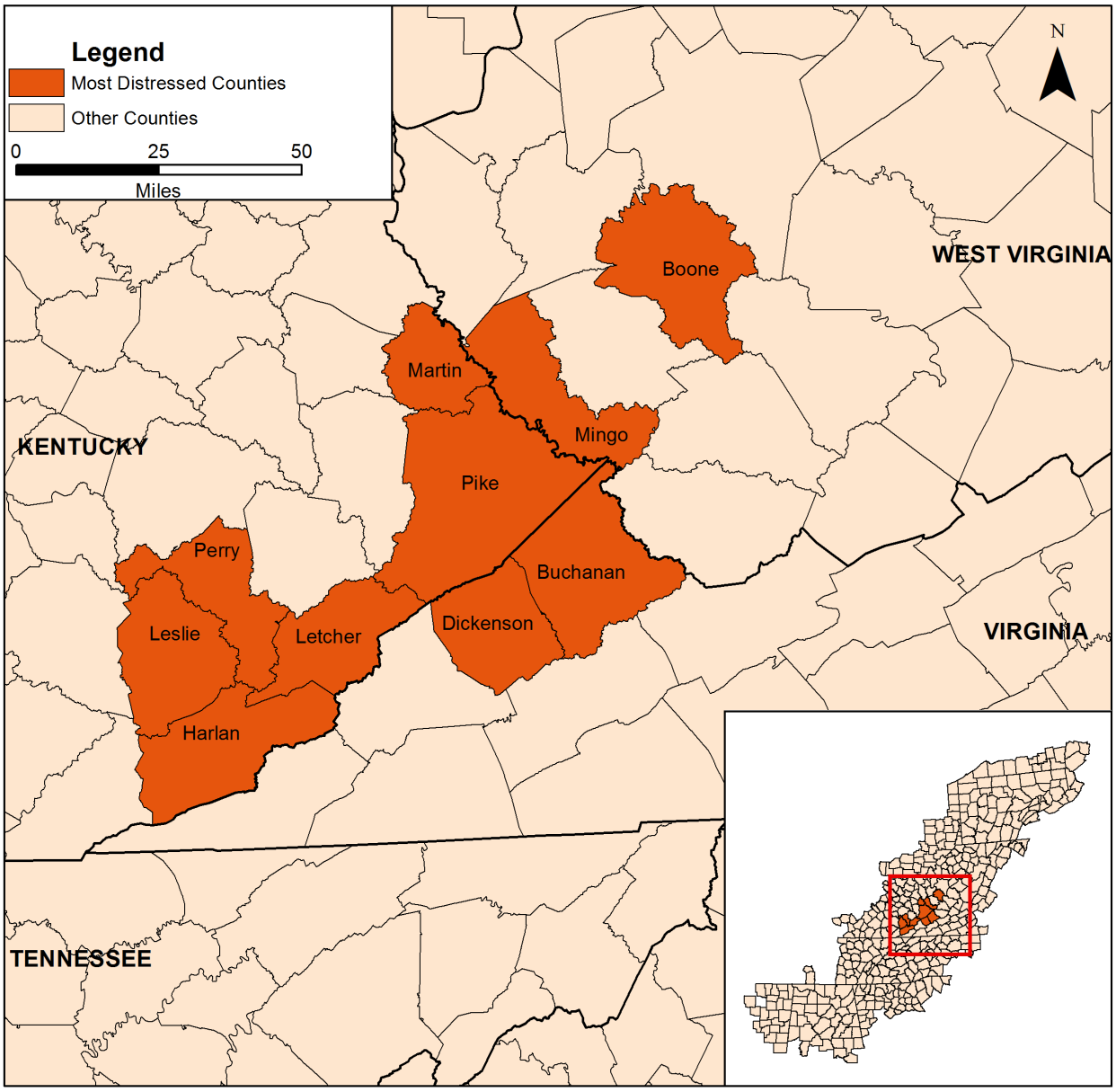
The second set of counties includes those that ranked in the top 20 in Risk, Impact, and Dependence in either 2005 or 2015. These are the counties that appear in bold in table 4, and all are present in Table 6 above. The 2005 and 2015 employment and wages data for these counties, along with 2015 coal industry data, are shown in Table 7 below. These counties are also shown in Figure 16.

Table 7: Top Coal-Distressed Appalachian CIE Counties – All Scores

	2005		2015		2015 Coal Industry	
Name	**Total Employment**	**Wages ($M)**	**Total Employment**	**Wages ($M)**	**Employment**	**Wages ($M)**
Boone County, West Virginia	8,977	369.7	5,925	272.1	1,278	101.3
Buchanan County, Virginia	7,926	268.8	6,856	307.2	1,012	95.5
Dickenson County, Virginia	3,368	98	3,606	140.2	405	31.8
Harlan County, Kentucky	8,625	264.3	6,227	217.9	605	41.3
Leslie County, Kentucky	2,270	77.5	1,683	59.7	164	11.4
Letcher County, Kentucky	6,769	202	4,471	156	239	12.9
Martin County, Kentucky	3,222	110.5	2,584	106.9	300	19.7
Mingo County, West Virginia	8,291	294.2	5,553	244.9	1,216	98.9
Perry County, Kentucky	13,680	432.4	12,000	450.5	1,205	78.7
Pike County, Kentucky	24,579	799.2	21,500	879.1	1,779	112.8

Note: Bold counties are "Distressed" and those in italics are "At-Risk" counties in the 2017 Appalachian Regional Commission classifications.

Figure 16: Top Coal-Distressed Appalachian CIE Counties – All Scores



Data Sources: Bureau of Labor Statistics, Bureau of Economic Analysis and Mine Safety and Health Administration

Summary

Through a comprehensive, quantitative, supply chain-based assessment of Appalachian Region counties, we identified industry and county characteristics related to the Coal Industry Ecosystem (CIE). Industry measures were developed to identify their relative positions in the coal industry supply chain, and these measures were weighted by employment and by employment change to construct county-based measures of CIE Dependence and CIE Impacts. We also developed a measure of risk that indicates each county's susceptibility to continued coal industry decline. This risk measure is built upon the Region-wide CIE industry self-sufficiency Dependence Score, and adds a locally-based CIE industry self-sufficiency measure and an independent dimension that varies with the inverse of coal mine productivity. The 2005 Risk Score was shown to have a strong negative correlation with the Impact Score, validating its use as an indicator of susceptibility to negative impacts of continuing coal industry decline.

Each of these dimensions, as measured by Dependence, Impact, and Risk Scores, was assessed independently, and used subsequently in the construction of an eight-class county typology. The typology was used to identify four dominant county classes. Class 1 Depressed counties are the most highly distressed, with High Dependence, High Negative Impact, and High Risk Scores. They have already suffered negative CIE-related economic impacts, and are susceptible to future coal-industry declines. Class 3 Vulnerable counties have not yet faced levels of economic hardship comparable to those in Class 1, but they remain vulnerable to continued coal-industry decline. Class 6 Hardship counties have experienced CIE-based decline, but their economies are no longer CIE-dependent, so they are not subject to increased CIE-driven hardship in future, though many continue to suffer the consequences of recent coal-industry decline. Counties in Class 8 are not strongly tied to the CIE — and have been and are expected to continue to be — the least affected by the coal industry fortunes.

The typology and the three county-level CIE Scores were used as a lens through which to identify the most distressed Appalachian counties whose condition can be most directly attributed to the CIE. These counties would be distressed by any number of measures, but given their strong ties to the CIE and vulnerability to continued coal-industry decline, they are particularly strong candidates for more in-depth analysis to identify policies and programs that might be implemented to dampen the negative impacts and alleviate some of the economic distress that can and will continue to be attributable to coal industry decline.

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Appendices

Appendix I. CIE Scores, All Industries

BEA Codes	Name	2005 CIE Score	2005 Employment	2015 CIE Score	2015 Employment
1111A0	Oilseed farming	0.01	70	0	276
1111B0	Grain farming	0.01	304	0	760
111200	Vegetable and melon farming	0	1,963	0	2,525
111300	Fruit and tree nut farming	0	1,604	0	1,768
111400	Greenhouse, nursery, and floriculture production	0	9,019	0	6,859
111900	Other crop farming	0.05	817	0.02	973
1121A0	Beef cattle ranching and farming, including feedlots and dual-purpose ranching and farming	0	963	0	1,175
112120	Dairy cattle and milk production	0	3,102	0	4,336
112A00	Animal production, except cattle and poultry and eggs	0	1,363	0	1,855
112300	Poultry and egg production	0	3,418	0	3,647
113000	Forestry and logging	0.04	7,850	0.02	6,169
114000	Fishing, hunting and trapping	0.01	138	0	171
115000	Support activities for agriculture and forestry	0.05	4,903	0.03	4,903
211000	Oil and gas extraction	0.16	4,984	0.06	10,692
212100	Coal mining	1	47,140	1	36,535
2122A0	Iron, gold, silver, and other metal ore mining	0.08	456	0.04	651
212230	Copper, nickel, lead, and zinc mining	0.69	19	0.02	717
212310	Stone mining and quarrying	0.08	14,588	0.07	7,972
2123A0	Other nonmetallic mineral mining and quarrying	0.03	3,697	0.02	2,478
213111	Drilling oil and gas wells	0	2,650	0	3,697
21311A	Other support activities for mining	0.08	11,628	0.04	21,421
221100	Electric power generation, transmission, and distribution	0.01	53,077	0	49,397
221200	Natural gas distribution	0.01	7,914	0.01	8,224
221300	Water, sewage and other systems	0	21,846	0	23,376
23	Construction	0	474,924	0	403,310
321100	Sawmills and wood preservation	0.01	21,687	0.01	17,295
321200	Veneer, plywood, and engineered wood product manufacturing	0	13,722	0	7,082
321910	Millwork	0	24,409	0	15,672
3219A0	All other wood product manufacturing	0	32,982	0	21,057

327100	Clay product and refractory manufacturing	0	15,012	0	8,652
327200	Glass and glass product manufacturing	0	16,658	0	13,522
327310	Cement manufacturing	0.01	1,960	0	2,111
327320	Ready-mix concrete manufacturing	0.01	9,563	0	7,223
327330	Concrete pipe, brick, and block manufacturing	0.01	2,937	0.01	2,277
327390	Other concrete product manufacturing	0	6,051	0	4,752
327400	Lime and gypsum product manufacturing	0.01	1,302	0	1,381
327910	Abrasive product manufacturing	0.03	727	0.02	532
327991	Cut stone and stone product manufacturing	0.01	3,459	0	3,844
327992	Ground or treated mineral and earth manufacturing	0.15	483	0.1	595
327993	Mineral wool manufacturing	0	2,420	0	1,163
327999	Miscellaneous nonmetallic mineral products	0.03	1,098	0.03	733
331110	Iron and steel mills and ferroalloy manufacturing	0.01	21,746	0.01	19,071
331200	Steel product manufacturing from purchased steel	0.02	11,776	0.01	8,922
33131A	Alumina refining and primary aluminum production	0.01	2,350	0.02	466
331314	Secondary smelting and alloying of aluminum	0.01	1,362	0	954
33131B	Aluminum product manufacturing from purchased aluminum	0	9,698	0	9,020
331411	Primary smelting and refining of copper	0.04	149	0.16	19
331419	Primary smelting and refining of nonferrous metal (except copper and aluminum)	0.01	1,787	0.05	285
331420	Copper rolling, drawing, extruding and alloying	0.01	8,205	0.01	3,262
331490	Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying	0.01	6,151	0.01	7,400
331510	Ferrous metal foundries	0.03	13,030	0.01	10,472
331520	Nonferrous metal foundries	0.01	6,430	0.01	4,838
33211A	All other forging, stamping, and sintering	0.01	9,383	0.01	9,807
332114	Custom roll forming	0.02	603	0.01	601
33211B	Crown and closure manufacturing and metal stamping	0.01	5,634	0.01	4,969

332200	Cutlery and handtool manufacturing	0.02	6,038	0.01	4,088
332310	Plate work and fabricated structural product manufacturing	0.01	21,666	0	20,661
332320	Ornamental and architectural metal products manufacturing	0.01	21,070	0	18,463
332410	Power boiler and heat exchanger manufacturing	0	3,125	0	2,578
332420	Metal tank (heavy gauge) manufacturing	0	2,705	0	3,481
332430	Metal can, box, and other metal container (light gauge) manufacturing	0.01	5,712	0	4,514
332500	Hardware manufacturing	0.02	3,683	0.01	1,908
332600	Spring and wire product manufacturing	0.01	6,621	0.01	4,380
332710	Machine shops	0.02	26,196	0.01	27,290
332720	Turned product and screw, nut, and bolt manufacturing	0.08	5,928	0.04	6,530
332800	Coating, engraving, heat treating and allied activities	0.02	11,205	0.01	9,999
33291A	Valve and fittings other than plumbing	0.02	6,671	0.01	5,861
332913	Plumbing fixture fitting and trim manufacturing	0.01	850	0	999
332991	Ball and roller bearing manufacturing	0.01	5,944	0.01	4,416
33299A	Ammunition, arms, ordnance, and accessories manufacturing	0	5,192	0	5,955
332996	Fabricated pipe and pipe fitting manufacturing	0.01	2,002	0	2,497
33299B	Other fabricated metal manufacturing	0.02	6,987	0.01	5,408
333111	Farm machinery and equipment manufacturing	0.01	2,647	0	3,409
333112	Lawn and garden equipment manufacturing	0	2,692	0	1,800
333120	Construction machinery manufacturing	0.1	6,384	0.05	7,599
333130	Mining and oil and gas field machinery manufacturing	0.37	4,905	0.29	5,405
33329A	Other industrial machinery manufacturing	0	9,207	0	6,852
333220	Plastics and rubber industry machinery manufacturing	0	2,122	0	1,568
333295	Semiconductor machinery manufacturing	0	243	0.01	104

33331A	Vending, commercial laundry, and other commercial and service industry machinery manufacturing	0	4,504	0	3,106
333313	Office machinery manufacturing	0.04	230	0.02	154
333314	Optical instrument and lens manufacturing	0	986	0	549
333315	Photographic and photocopying equipment manufacturing	0.01	308	0	47
33341A	Air purification and ventilation equipment manufacturing	0	2,492	0	1,759
333414	Heating equipment (except warm air furnaces) manufacturing	0	3,509	0	1,934
333415	Air conditioning, refrigeration, and warm air heating equipment manufacturing	0	8,383	0	5,945
333511	Industrial mold manufacturing	0	4,750	0	3,268
33351A	Metal cutting and forming machine tool manufacturing	0.01	3,058	0	3,553
333514	Special tool, die, jig, and fixture manufacturing	0	8,785	0	6,668
33351B	Cutting and machine tool accessory, rolling mill, and other metalworking machinery manufacturing	0.03	6,286	0.02	5,229
333611	Turbine and turbine generator set units manufacturing	0	3,558	0	4,866
333612	Speed changer, industrial high-speed drive, and gear manufacturing	0.09	740	0.02	1,436
333613	Mechanical power transmission equipment manufacturing	0.02	1,742	0.02	954
333618	Other engine equipment manufacturing	0.02	6,383	0.01	6,112
33391A	Pump and pumping equipment manufacturing	0.01	1,931	0	2,084
333912	Air and gas compressor manufacturing	0	3,889	0	3,739
333920	Material handling equipment manufacturing	0.06	9,012	0.03	9,722
333991	Power-driven handtool manufacturing	0	1,934	0	616
33399A	Other general purpose machinery manufacturing	0.01	4,612	0	5,276
333993	Packaging machinery manufacturing	0	1,381	0	1,294
333994	Industrial process furnace and oven manufacturing	0	1,848	0	1,593
33399B	Fluid power process machinery	0.03	3,296	0.02	3,014
334111	Electronic computer manufacturing	0	5,787	0	2,161

334112	Computer storage device manufacturing	0.01	547	0	733
33411A	Computer terminals and other computer peripheral equipment manufacturing	0.04	1,754	0.01	3,157
334210	Telephone apparatus manufacturing	0.01	3,097	0	3,012
334220	Broadcast and wireless communications equipment	0	3,828	0	2,954
334290	Other communications equipment manufacturing	0.01	1,208	0.01	836
334300	Audio and video equipment manufacturing	0	3,218	0	669
33441A	Other electronic component manufacturing	0.01	15,136	0.01	8,613
334413	Semiconductor and related device manufacturing	0.08	1,303	0.03	1,573
334418	Printed circuit assembly (electronic assembly) manufacturing	0.01	4,594	0	5,162
334510	Electromedical and electrotherapeutic apparatus manufacturing	0	2,294	0	4,410
334511	Search, detection, and navigation instruments manufacturing	0	4,965	0	3,104
334512	Automatic environmental control manufacturing	0.01	1,292	0.01	423
334513	Industrial process variable instruments manufacturing	0	5,035	0	5,175
334514	Totalizing fluid meter and counting device manufacturing	0.01	2,824	0	2,378
334515	Electricity and signal testing instruments manufacturing	0	2,079	0	684
334516	Analytical laboratory instrument manufacturing	0	1,391	0	1,213
334517	Irradiation apparatus manufacturing	0.01	152	0.01	124
33451A	Watch, clock, and other measuring and controlling device manufacturing	0	2,621	0	1,931
334610	Manufacturing and reproducing magnetic and optical media	0	6,035	0	1,952
335110	Electric lamp bulb and part manufacturing	0	2,384	0	1,042
335120	Lighting fixture manufacturing	0.01	3,307	0	4,453
335210	Small electrical appliance manufacturing	0	1,823	0	2,523
335221	Household cooking appliance manufacturing	0	4,456	0	3,794

335222	Household refrigerator and home freezer manufacturing	0	2,611	0	2,099
335224	Household laundry equipment manufacturing	0	83	1	0
335228	Other major household appliance manufacturing	0	1,351	0	1,102
335311	Power, distribution, and specialty transformer manufacturing	0	2,096	0	2,142
335312	Motor and generator manufacturing	0.01	6,813	0	5,373
335313	Switchgear and switchboard apparatus manufacturing	0.01	3,233	0	5,012
335314	Relay and industrial control manufacturing	0.01	4,685	0.01	6,433
335911	Storage battery manufacturing	0.01	2,537	0	1,935
335912	Primary battery manufacturing	0	1,804	0	1,064
335920	Communication and energy wire and cable manufacturing	0	4,138	0	3,100
335930	Wiring device manufacturing	0	5,521	0	4,994
335991	Carbon and graphite product manufacturing	0	2,708	0	2,133
335999	All other miscellaneous electrical equipment and component manufacturing	0.01	1,632	0.01	1,470
336111	Automobile manufacturing	0	15,477	0	20,404
336112	Light truck and utility vehicle manufacturing	0	3,457	0	3,446
336120	Heavy duty truck manufacturing	0	7,757	0	6,712
336211	Motor vehicle body manufacturing	0	4,928	0	6,425
336212	Truck trailer manufacturing	0	4,080	0	4,459
336213	Motor home manufacturing	0	2,210	0	1,815
336214	Travel trailer and camper manufacturing	0	3,649	0	2,807
336310	Motor vehicle gasoline engine and engine parts manufacturing	0.01	10,772	0	11,429
336320	Motor vehicle electrical and electronic equipment manufacturing	0.01	14,693	0	12,831
3363A0	Motor vehicle steering, suspension component (except spring), and brake systems manufacturing	0.01	12,621	0	11,778
336350	Motor vehicle transmission and power train parts manufacturing	0.01	8,764	0	10,050
336360	Motor vehicle seating and interior trim manufacturing	0	8,614	0	12,429
336370	Motor vehicle metal stamping	0	8,536	0	11,255
336390	Other motor vehicle parts manufacturing	0.01	18,024	0.01	16,873

336411	Aircraft manufacturing	0	3,922	0	4,104
336412	Aircraft engine and engine parts manufacturing	0	3,610	0	4,634
336413	Other aircraft parts and auxiliary equipment manufacturing	0	4,510	0	4,630
336414	Guided missile and space vehicle manufacturing	0	2,291	0	2,171
33641A	Propulsion units and parts for space vehicles and guided missiles	0	1,902	0	2,654
336500	Railroad rolling stock manufacturing	0.01	10,801	0.01	10,269
336611	Ship building and repairing	0.03	533	0.01	988
336612	Boat building	0	8,665	0	3,037
336991	Motorcycle, bicycle, and parts manufacturing	0	647	0	744
336992	Military armored vehicle, tank, and tank component manufacturing	0	201	0	815
336999	All other transportation equipment manufacturing	0	556	0	524
337110	Wood kitchen cabinet and countertop manufacturing	0	17,103	0	11,161
337121	Upholstered household furniture manufacturing	0	36,824	0	25,162
337122	Nonupholstered wood household furniture manufacturing	0	21,657	0	5,442
33712A	Other household nonupholstered furniture	0	2,917	0	1,134
337127	Institutional furniture manufacturing	0	4,812	0	1,694
33721A	Office furniture and custom architectural woodwork and millwork manufacturing	0	4,920	0	5,331
337215	Showcase, partition, shelving, and locker manufacturing	0	8,294	0	5,972
337900	Other furniture related product manufacturing	0	5,021	0	3,908
339112	Surgical and medical instrument manufacturing	0	2,826	0	3,065
339113	Surgical appliance and supplies manufacturing	0	10,820	0	8,057
339114	Dental equipment and supplies manufacturing	0	459	0	330
339115	Ophthalmic goods manufacturing	0	3,687	0	2,375
339116	Dental laboratories	0	3,370	0	2,997
339910	Jewelry and silverware manufacturing	0	480	0	308
339920	Sporting and athletic goods manufacturing	0	3,502	0	2,379

339930	Doll, toy, and game manufacturing	0	1,226	0	463
339940	Office supplies (except paper) manufacturing	0	1,122	0	1,240
339950	Sign manufacturing	0	5,877	0	5,702
339990	All other miscellaneous manufacturing	0.01	12,453	0.01	8,707
311111	Dog and cat food manufacturing	0	2,108	0	2,761
311119	Other animal food manufacturing	0	2,798	0	2,502
311210	Flour milling and malt manufacturing	0	822	0	633
311221	Wet corn milling	0.02	171	0.01	284
31122A	Soybean and other oilseed processing	0.01	343	0	469
311225	Fats and oils refining and blending	0	415	0	513
311230	Breakfast cereal manufacturing	0	201	0	4
311300	Sugar and confectionery product manufacturing	0	6,249	0	5,771
311410	Frozen food manufacturing	0	7,119	0	6,807
311420	Fruit and vegetable canning, pickling, and drying	0	5,382	0	3,886
31151A	Fluid milk and butter manufacturing	0	5,485	0	5,809
311513	Cheese manufacturing	0	1,428	0	1,629
311514	Dry, condensed, and evaporated dairy product manufacturing	0	410	0	344
311520	Ice cream and frozen dessert manufacturing	0	2,044	0	1,658
31161A	Animal (except poultry) slaughtering, rendering, and processing	0	17,068	0	12,410
311615	Poultry processing	0	46,740	0	43,820
311700	Seafood product preparation and packaging	0	1,217	0	318
311810	Bread and bakery product manufacturing	0	20,768	0	17,311
3118A0	Cookie, cracker, pasta, and tortilla manufacturing	0	4,715	0	6,180
311910	Snack food manufacturing	0	3,587	0	3,452
311920	Coffee and tea manufacturing	0	971	0	1,776
311930	Flavoring syrup and concentrate manufacturing	0.01	60	0	63
311940	Seasoning and dressing manufacturing	0	1,246	0	2,142
311990	All other food manufacturing	0	2,255	0	2,750
312110	Soft drink and ice manufacturing	0	11,666	0	8,295
312120	Breweries	0	1,328	0	2,702
312130	Wineries	0	1,571	0	2,538

312140	Distilleries	1	0	0	468
312200	Tobacco product manufacturing	0	7,628	0	2,315
313100	Fiber, yarn, and thread mills	0	20,562	0	11,055
313200	Fabric mills	0	35,751	0	19,074
313300	Textile and fabric finishing and fabric coating mills	0	15,324	0	8,057
314110	Carpet and rug mills	0	36,463	0	24,485
314120	Curtain and linen mills	0	8,913	0	2,821
314900	Other textile product mills	0.01	12,591	0.01	8,856
315000	Apparel manufacturing	0	31,824	0	10,138
316000	Leather and allied product manufacturing	0	3,336	0	1,899
322110	Pulp mills	0.01	519	0	744
322120	Paper mills	0.01	9,924	0	6,173
322130	Paperboard mills	0.01	3,586	0.01	2,938
322210	Paperboard container manufacturing	0.01	16,271	0	13,889
322220	Paper bag and coated and treated paper manufacturing	0.01	6,628	0.01	5,578
322230	Stationery product manufacturing	0	4,831	0	3,158
322291	Sanitary paper product manufacturing	0	3,412	0	4,473
322299	All other converted paper product manufacturing	0	2,281	0	2,102
323110	Printing	0.01	40,714	0	28,043
323120	Support activities for printing	0.01	2,836	0	1,901
324110	Petroleum refineries	0.09	2,587	0.05	2,561
324121	Asphalt paving mixture and block manufacturing	0	1,753	0	1,701
324122	Asphalt shingle and coating materials manufacturing	0	1,285	0	815
324190	Other petroleum and coal products manufacturing	0.03	3,739	0.02	3,940
325110	Petrochemical manufacturing	0.06	902	0.03	902
325120	Industrial gas manufacturing	0.02	2,827	0.02	1,400
325130	Synthetic dye and pigment manufacturing	0.01	3,434	0	2,735
325180	Other basic inorganic chemical manufacturing	0	14,013	0.01	4,511
325190	Other basic organic chemical manufacturing	0.01	4,032	0	10,626
325211	Plastics material and resin manufacturing	0.01	9,692	0	9,172
3252A0	Synthetic rubber and artificial and synthetic fibers and filaments manufacturing	0.01	9,090	0	8,120
325310	Fertilizer manufacturing	0.01	1,578	0.01	723

325320	Pesticide and other agricultural chemical manufacturing	0	492	0	482
325411	Medicinal and botanical manufacturing	0	542	0	684
325412	Pharmaceutical preparation manufacturing	0	10,387	0	12,033
325413	In-vitro diagnostic substance manufacturing	0	554	0	861
325414	Biological product (except diagnostic) manufacturing	0	2,359	0	2,797
325510	Paint and coating manufacturing	0.01	3,688	0.01	2,353
325520	Adhesive manufacturing	0.01	2,180	0	1,793
325610	Soap and cleaning compound manufacturing	0	4,884	0	4,851
325620	Toilet preparation manufacturing	0	1,523	0	1,220
325910	Printing ink manufacturing	0.01	566	0.01	458
3259A0	All other chemical product and preparation manufacturing	0.07	7,567	0.03	8,035
326110	Plastics packaging materials and unlaminated film and sheet manufacturing	0.01	12,971	0	12,541
326120	Plastics pipe, pipe fitting, and unlaminated profile shape manufacturing	0.01	6,110	0	5,525
326130	Laminated plastics plate, sheet (except packaging), and shape manufacturing	0	3,902	0	2,408
326140	Polystyrene foam product manufacturing	0	3,030	0	3,704
326150	Urethane and other foam product (except polystyrene) manufacturing	0	5,381	0	5,159
326160	Plastics bottle manufacturing	0	2,127	0	2,485
326190	Other plastics product manufacturing	0.01	43,730	0	39,822
326210	Tire manufacturing	0.04	13,308	0.02	12,747
326220	Rubber and plastics hoses and belting manufacturing	0.24	2,191	0.13	1,890
326290	Other rubber product manufacturing	0.01	11,474	0.01	12,104
420000	Wholesale trade	0.02	349,063	0.01	332,949
441000	Motor vehicle and parts dealers	0	160,235	0	158,078
445000	Food and beverage stores	0	226,916	0	222,990
452000	General merchandise stores	0	273,268	0	273,303
4A0000	Other retail	0	624,576	0	553,898
481000	Air transportation	0.01	16,055	0.01	8,361
482000	Rail transportation	1	0	0.33	39
483000	Water transportation	0.07	1,773	0.06	1,353

484000	Truck transportation	0.01	143,624	0.01	131,836
485000	Transit and ground passenger transportation	0	55,817	0	44,943
486000	Pipeline transportation	0	28,137	0.02	4,193
48A000	Scenic and sightseeing transportation and support activities for transportation	0.01	63,855	0.01	32,906
492000	Couriers and messengers	0.01	59,936	0.01	32,364
493000	Warehousing and storage	0	84,721	0	70,431
511110	Newspaper publishers	0.01	28,180	0	17,466
511120	Periodical Publishers	0.01	5,355	0.01	3,759
511130	Book publishers	0	1,506	0	1,527
5111A0	Directory, mailing list, and other publishers	0.01	3,648	0.01	1,431
511200	Software publishers	0	6,772	0	8,791
512100	Motion picture and video industries	0	10,296	0	9,183
512200	Sound recording industries	0	422	0	404
515100	Radio and television broadcasting	0.01	16,722	0	13,639
515200	Cable and other subscription programming	0.01	3,823	0.01	1,917
517110	Wired telecommunications carriers	0	47,071	0	34,902
517210	Wireless telecommunications carriers (except satellite)	0	12,261	0	9,669
517A00	Satellite, telecommunications resellers, and all other telecommunications	0.01	5,901	0	3,041
518200	Data processing, hosting, and related services	0.01	13,105	0.01	11,706
5191A0	News syndicates, libraries, archives and all other information services	0	11,647	0	10,319
519130	Internet publishing and broadcasting and Web search portals	0.04	589	0.03	1,876
52A000	Monetary authorities and depository credit intermediation	0.01	146,920	0	137,403
522A00	Nondepository credit intermediation and related activities	0.02	44,736	0.01	41,163
523A00	Securities and commodity contracts intermediation and brokerage	0.03	11,265	0.02	8,910
523900	Other financial investment activities	0.04	6,361	0.02	11,941
524100	Insurance carriers	0	66,351	0	56,224
524200	Insurance agencies, brokerages, and related activities	0.01	52,007	0	57,064

525000	Funds, trusts, and other financial vehicles	0	1,865	0	146
531	Housing and other real estate	0	68,345	0	67,767
532100	Automotive equipment rental and leasing	0.01	9,049	0.01	10,728
532A00	Consumer goods and general rental centers	0.01	25,237	0	15,614
532400	Commercial and industrial machinery and equipment rental and leasing	0.17	4,466	0.06	8,539
533000	Lessors of nonfinancial intangible assets	0.04	951	0.03	823
541100	Legal services	0.01	61,252	0.01	55,498
541511	Custom computer programming services	0	19,540	0	25,305
541512	Computer systems design services	0.01	19,138	0.01	36,014
54151A	Other computer related services, including facilities management	0.01	7,536	0.01	6,590
541200	Accounting, tax preparation, bookkeeping, and payroll services	0.02	44,687	0.01	46,303
541300	Architectural, engineering, and related services	0.02	86,817	0.01	91,468
541400	Specialized design services	0.01	6,710	0.01	4,753
541610	Management consulting services	0.01	31,809	0.01	34,582
5416A0	Environmental and other technical consulting services	0.02	5,752	0.01	8,797
541700	Scientific research and development services	0	23,269	0	27,961
541800	Advertising, public relations, and related services	0.02	16,106	0.01	14,353
5419A0	Marketing research and all other miscellaneous professional, scientific, and technical services	0.02	6,719	0.01	7,948
541920	Photographic services	0	6,197	0	3,130
541940	Veterinary services	0	19,891	0	25,826
550000	Management of companies and enterprises	0.04	87,229	0.02	128,312
561100	Office administrative services	0.01	18,614	0.01	17,390
561200	Facilities support services	0.01	5,129	0	9,969
561300	Employment services	0.01	190,456	0	218,494
561400	Business support services	0.01	59,139	0.01	66,562
561500	Travel arrangement and reservation services	0.01	9,463	0.01	7,336
561600	Investigation and security services	0.01	37,926	0.01	44,104
561700	Services to buildings and dwellings	0.01	101,402	0.01	117,449
561900	Other support services	0.01	16,083	0.01	16,230
562000	Waste management and remediation services	0.01	25,754	0.01	31,623

611100	Elementary and secondary schools	0	615,304	0	583,384
611A00	Junior colleges, colleges, universities, and professional schools	0	207,638	0	246,271
611B00	Other educational services	0	33,516	0	35,063
621100	Offices of physicians	0	163,952	0	192,373
621200	Offices of dentists	0	51,720	0	57,648
621300	Offices of other health practitioners	0	45,584	0	63,090
621400	Outpatient care centers	0	47,189	0	65,331
621500	Medical and diagnostic laboratories	0	10,297	0	14,457
621600	Home health care services	0	53,212	0	74,457
621900	Other ambulatory health care services	0	26,547	0	31,922
622000	Hospitals	0	441,832	0	457,206
623A00	Nursing and community care facilities	0	207,735	0	223,211
623B00	Residential mental retardation, mental health, substance abuse and other facilities	0	73,667	0	80,872
624100	Individual and family services	0	93,280	0	138,691
624A00	Community food, housing, and other relief services, including rehabilitation services	0	42,684	0	39,971
624400	Child day care services	0	56,268	0	58,492
711100	Performing arts companies	0.01	4,769	0	5,031
711200	Spectator sports	0	6,287	0	5,497
711A00	Promoters of performing arts and sports and agents for public figures	0	4,367	0	7,695
711500	Independent artists, writers, and performers	0.01	1,299	0.01	1,195
712000	Museums, historical sites, zoos, and parks	0	12,166	0	13,610
713100	Amusement parks and arcades	0	6,095	0	7,069
713200	Gambling industries (except casino hotels)	0	6,974	0	11,595
713900	Other amusement and recreation industries	0	75,640	0	74,715
721000	Accommodation	0	91,620	0	105,133
722110	Full-service restaurants	0	313,949	0	351,225
722211	Limited-service restaurants	0	328,359	0	382,610
722A00	All other food and drinking places	0	49,502	0	56,232
811100	Automotive repair and maintenance	0	59,879	0	57,928

811200	Electronic and precision equipment repair and maintenance	0.01	6,438	0	6,769
811300	Commercial and industrial machinery and equipment repair and maintenance	0.01	17,026	0	18,186
811400	Personal and household goods repair and maintenance	0.01	4,703	0.01	3,488
812100	Personal care services	0	36,110	0	37,560
812200	Death care services	0	16,392	0	16,337
812300	Dry-cleaning and laundry services	0	22,385	0	17,940
812900	Other personal services	0	9,854	0	10,491
813100	Religious organizations	0	10,455	0	12,434
813A00	Grantmaking, giving, and social advocacy organizations	0	21,479	0	19,829
813B00	Civic, social, professional, and similar organizations	0	56,412	0	51,686
814000	Private households	0	14,086	0	14,060
491000	Postal Service	0.01	59,304	0	45,610
92	Government	0	465,186	0	473,556

Data Sources: Bureau of Labor Statistics and Bureau of Economic Analysis

Appendix II. All Dependence, Impact, and Risk Scores

FIPS	County Names	2015 Global Dependence	2015 Local Dependence	Impact Score	2015 Mine-Productivity Risk	2015 Total Risk
1007	Bibb, AL	0.25	0	-0.18	0	0.25
1009	Blount, AL	0.92	0.21	0.61	77.62	1.65
1015	Calhoun, AL	0.25	0	-0.08	0	0.25
1017	Chambers, AL	0.29	0	-0.04	0	0.29
1019	Cherokee, AL	0.19	0	-0.07	0	0.19
1021	Chilton, AL	0.25	0	0.1	0	0.25
1027	Clay, AL	0.24	0	-0.1	0	0.24
1029	Cleburne, AL	0.16	0	-0.12	0	0.16
1033	Colbert, AL	0.33	0	0.06	0	0.33
1037	Coosa, AL	0.19	0	0	0	0.19
1043	Cullman, AL	0.26	0	-0.12	0	0.26
1049	DeKalb, AL	0.26	0	0.02	0	0.26
1051	Elmore, AL	0.18	0	0.03	0	0.18
1055	Etowah, AL	0.31	0	0.03	0	0.31
1057	Fayette, AL	0.25	0	-6.69	0	0.25
1059	Franklin, AL	0.35	0	0.05	40.61	0.49
1065	Hale, AL	0.35	0	0	0	0.35
1071	Jackson, AL	0.24	0	-0.14	7.62	0.26
1073	Jefferson, AL	0.7	0.16	-0.14	78.27	1.26
1075	Lamar, AL	0.69	0	0.02	0	0.69
1077	Lauderdale, AL	0.23	0	-0.03	0	0.23
1079	Lawrence, AL	0.22	0	-0.18	0	0.22
1083	Limestone, AL	0.24	0	-0.11	0	0.24
1087	Macon, AL	0.09	0	-0.08	0	0.09
1089	Madison, AL	0.3	0	0.03	0	0.3
1093	Marion, AL	0.34	0	-0.38	0	0.34
1095	Marshall, AL	0.24	0	-0.03	0	0.24
1103	Morgan, AL	0.33	0	-0.02	0	0.33
1107	Pickens, AL	0.28	0	-0.13	0	0.28
1111	Randolph, AL	0.24	0	0	0	0.24
1115	St. Clair, AL	0.29	0	0.09	0	0.29
1117	Shelby, AL	0.59	0.05	0.31	47.52	0.87
1121	Talladega, AL	0.3	0	-0.03	0	0.3
1123	Tallapoosa, AL	0.26	0	0	0	0.26

1125	Tuscaloosa, AL	1.92	0.62	0.39	81.27	3.5
1127	Walker, AL	2.06	0.62	-0.33	76.29	3.65
1133	Winston, AL	0.77	0.16	0.34	76.04	1.35
13011	Banks, GA	0.19	0	-0.01	0	0.19
13013	Barrow, GA	0.3	0	0.14	0	0.3
13015	Bartow, GA	0.41	0	0.14	0	0.41
13045	Carroll, GA	0.25	0	0.08	0	0.25
13047	Catoosa, GA	0.2	0	-0.02	0	0.2
13055	Chattooga, GA	0.18	0	-0.04	0	0.18
13057	Cherokee, GA	0.25	0	0.12	0	0.25
13083	Dade, GA	0.21	0	-0.05	0	0.21
13085	Dawson, GA	0.19	0	0.05	0	0.19
13097	Douglas, GA	0.27	0	0.04	0	0.27
13105	Elbert, GA	0.57	0	-0.05	0	0.57
13111	Fannin, GA	0.2	0	0.03	0	0.2
13115	Floyd, GA	0.23	0	-0.02	0	0.23
13117	Forsyth, GA	0.35	0	0.31	0	0.35
13119	Franklin, GA	0.31	0	-0.05	0	0.31
13123	Gilmer, GA	0.21	0	-0.08	0	0.21
13129	Gordon, GA	0.25	0	-0.04	0	0.25
13135	Gwinnett, GA	0.39	0	0.05	0	0.39
13137	Habersham, GA	0.18	0	-0.08	0	0.18
13139	Hall, GA	0.25	0	-0.04	0	0.25
13143	Haralson, GA	0.3	0	0.02	0	0.3
13147	Hart, GA	0.26	0	-0.08	0	0.26
13149	Heard, GA	0.4	0	-0.25	0	0.4
13157	Jackson, GA	0.47	0	0.54	0	0.47
13187	Lumpkin, GA	0.17	0	-0.11	0	0.17
13195	Madison, GA	0.24	0	-0.16	0	0.24
13213	Murray, GA	0.5	0	0.18	0	0.5
13223	Paulding, GA	0.2	0	0.1	0	0.2
13227	Pickens, GA	0.32	0	-0.1	0	0.32
13233	Polk, GA	0.24	0	-0.04	0	0.24
13241	Rabun, GA	0.16	0	-0.1	0	0.16
13257	Stephens, GA	0.29	0	-0.1	0	0.29
13281	Towns, GA	0.16	0	-0.09	0	0.16
13291	Union, GA	0.19	0	0	0	0.19
13295	Walker, GA	0.19	0	-0.02	0	0.19
13311	White, GA	0.3	0	0.21	0	0.3
13313	Whitfield, GA	0.28	0	-0.03	0	0.28
21001	Adair, KY	0.18	0	-0.08	0	0.18

21011	Bath, KY	0.14	0	-0.01	0	0.14
21013	Bell, KY	5.12	1.54	-4.66	82.7	9.5
21019	Boyd, KY	0.62	0	-0.11	22.65	0.76
21025	Breathitt, KY	1.51	0.32	0.71	61.27	2.44
21043	Carter, KY	0.56	0.1	0.1	87.09	1.05
21045	Casey, KY	0.31	0	-0.03	0	0.31
21049	Clark, KY	0.37	0	0.02	0	0.37
21051	Clay, KY	0.54	0	-2.44	50.1	0.82
21053	Clinton, KY	0.16	0	0.07	0	0.16
21057	Cumberland, KY	0.17	0	0.04	0	0.17
21061	Edmonson, KY	0.15	0	0.05	0	0.15
21063	Elliott, KY	0.07	0	-2.29	0	0.07
21065	Estill, KY	0.18	0	-0.05	50	0.26
21069	Fleming, KY	0.23	0	-0.13	0	0.23
21071	Floyd, KY	4.02	1.23	-1.8	65.64	6.74
21079	Garrard, KY	0.28	0	0.05	0	0.28
21087	Green, KY	0.13	0	-0.03	0	0.13
21089	Greenup, KY	0.29	0	-0.11	0	0.29
21095	Harlan, KY	9.84	2.61	-7.73	75.2	17.68
21099	Hart, KY	0.19	0	-0.02	0	0.19
21109	Jackson, KY	0.2	0	-0.33	0	0.2
21115	Johnson, KY	2.03	0.41	-0.63	86.37	3.79
21119	Knott, KY	6.92	0.83	-32.8	27.17	8.88
21121	Knox, KY	0.68	0.1	-0.72	100	1.36
21125	Laurel, KY	1.1	0.16	0.08	100	2.21
21127	Lawrence, KY	0.49	0.06	-0.72	63.24	0.8
21129	Lee, KY	0.49	0.02	-0.95	19.59	0.59
21131	Leslie, KY	9.95	2.01	-14.76	52.91	15.51
21133	Letcher, KY	5.62	1.49	-12.36	91.6	10.93
21135	Lewis, KY	0.25	0	0.04	0	0.25
21137	Lincoln, KY	0.32	0	0.18	0	0.32
21147	McCreary, KY	1.18	0.15	0.49	100	2.36
21151	Madison, KY	0.37	0.02	0.11	7.42	0.4
21153	Magoffin, KY	1.75	0.34	-0.28	64.18	2.89
21159	Martin, KY	11.86	3	-8.57	87.48	22.9
21165	Menifee, KY	0.38	0	0.03	0	0.38
21169	Metcalfe, KY	0.26	0	-0.09	0	0.26
21171	Monroe, KY	0.32	0	-0.23	0	0.32
21173	Montgomery, KY	0.72	0	0.11	0	0.72
21175	Morgan, KY	2.71	0.56	2.32	78.71	4.87
21181	Nicholas, KY	0.15	0	-0.03	0	0.15

21189	Owsley, KY	4.39	0.24	4	36.5	6.01
21193	Perry, KY	10.3	2.57	-2.57	40	14.79
21195	Pike, KY	8.59	2.87	-8.07	77.21	15.66
21197	Powell, KY	0.36	0	0.14	0	0.36
21199	Pulaski, KY	0.23	0	-0.06	0	0.23
21201	Robertson, KY	0.11	0	0.03	0	0.11
21203	Rockcastle, KY	0.22	0	0.02	0	0.22
21205	Rowan, KY	0.23	0	-0.01	0	0.23
21207	Russell, KY	0.23	0	-0.08	0	0.23
21231	Wayne, KY	0.25	0	-0.08	0	0.25
21235	Whitley, KY	1.59	0.32	1.19	100	3.2
21237	Wolfe, KY	2.59	0.38	2.3	75.55	4.56
24001	Allegany, MD	0.23	0.01	-0.12	42.96	0.32
24023	Garrett, MD	1.14	0.26	-1.59	77.2	2.03
24043	Washington, MD	0.31	0	-0.01	0	0.31
28003	Alcorn, MS	0.27	0	0.01	0	0.27
28009	Benton, MS	0.22	0	-0.22	0	0.22
28013	Calhoun, MS	0.29	0	-0.1	0	0.29
28017	Chickasaw, MS	0.16	0	-0.01	0	0.16
28019	Choctaw, MS	11.9	0.38	1.78	5.57	12.61
28025	Clay, MS	0.25	0	-0.1	0	0.25
28057	Itawamba, MS	0.23	0	-0.15	0	0.23
28069	Kemper, MS	2.59	0.21	3.51	100	5.2
28081	Lee, MS	0.32	0	0.02	0	0.32
28087	Lowndes, MS	0.28	0	0.07	0	0.28
28093	Marshall, MS	0.23	0	0.02	0	0.23
28095	Monroe, MS	0.25	0	-0.17	0	0.25
28097	Montgomery, MS	0.25	0	-0.11	0	0.25
28103	Noxubee, MS	0.23	0	-0.18	0	0.23
28105	Oktibbeha, MS	0.23	0	0.05	0	0.23
28107	Panola, MS	0.29	0	-0.15	0	0.29
28115	Pontotoc, MS	0.13	0	-0.02	0	0.13
28117	Prentiss, MS	0.22	0	-0.02	0	0.22
28139	Tippah, MS	0.28	0	-0.01	0	0.28
28141	Tishomingo, MS	0.24	0	0.02	0	0.24
28145	Union, MS	0.27	0	0.13	0	0.27
28155	Webster, MS	0.31	0	-0.04	0	0.31
28159	Winston, MS	0.6	0	-0.12	0	0.6

28161	Yalobusha, MS	0.22	0	0	0	0.22
36003	Allegany, NY	0.15	0	-0.12	0	0.15
36007	Broome, NY	0.23	0	-0.08	0	0.23
36009	Cattaraugus, NY	0.2	0	-0.09	0	0.2
36013	Chautauqua, NY	0.26	0	-0.03	0	0.26
36015	Chemung, NY	0.39	0	0.23	0	0.39
36017	Chenango, NY	0.47	0	0.34	0	0.47
36023	Cortland, NY	0.22	0	-0.03	0	0.22
36025	Delaware, NY	0.23	0	-0.07	0	0.23
36077	Otsego, NY	0.13	0	-0.05	0	0.13
36095	Schoharie, NY	0.16	0	-0.06	0	0.16
36097	Schuyler, NY	0.14	0	-0.05	0	0.14
36101	Steuben, NY	0.25	0	0.03	0	0.25
36107	Tioga, NY	0.35	0	0.18	0	0.35
36109	Tompkins, NY	0.17	0	-0.01	0	0.17
37003	Alexander, NC	0.15	0	0.01	0	0.15
37005	Alleghany, NC	0.15	0	-0.05	0	0.15
37009	Ashe, NC	0.36	0	-0.06	0	0.36
37011	Avery, NC	0.19	0	-0.05	0	0.19
37021	Buncombe, NC	0.26	0	0.08	0	0.26
37023	Burke, NC	0.16	0	-0.11	0	0.16
37027	Caldwell, NC	0.24	0	-0.1	0	0.24
37039	Cherokee, NC	0.23	0	-0.11	0	0.23
37043	Clay, NC	0.16	0	-0.03	0	0.16
37059	Davie, NC	0.25	0	-0.02	0	0.25
37067	Forsyth, NC	0.32	0	0.05	0	0.32
37075	Graham, NC	0.2	0	-0.14	0	0.2
37087	Haywood, NC	0.17	0	-0.05	0	0.17
37089	Henderson, NC	0.29	0	-0.06	0	0.29
37099	Jackson, NC	0.16	0	-0.1	0	0.16
37111	McDowell, NC	0.22	0	0.01	0	0.22
37113	Macon, NC	0.17	0	-0.15	0	0.17
37115	Madison, NC	0.16	0	-0.23	0	0.16
37121	Mitchell, NC	0.44	0	-0.03	0	0.44
37149	Polk, NC	0.19	0	-0.01	0	0.19
37161	Rutherford, NC	0.31	0	-0.15	0	0.31
37169	Stokes, NC	0.24	0	0.06	0	0.24
37171	Surry, NC	0.39	0.02	0.06	8.17	0.42

37173	Swain, NC	0.1	0	0.04	0	0.1
37175	Transylvania, NC	0.19	0	-0.06	0	0.19
37189	Watauga, NC	0.19	0	-0.03	0	0.19
37193	Wilkes, NC	0.33	0	-0.3	0	0.33
37197	Yadkin, NC	0.21	0	0.01	0	0.21
37199	Yancey, NC	0.19	0	-0.15	0	0.19
39001	Adams, OH	0.22	0	-0.08	0	0.22
39007	Ashtabula, OH	0.28	0	-0.04	0	0.28
39009	Athens, OH	0.33	0.05	-0.07	30.88	0.43
39013	Belmont, OH	3.38	0.35	0.14	13.78	3.86
39015	Brown, OH	0.59	0.1	0.37	50	0.89
39019	Carroll, OH	1.9	0.47	1.83	68.88	3.23
39025	Clermont, OH	0.3	0	0.05	0	0.3
39029	Columbiana, OH	0.36	0.02	-0.21	6.51	0.39
39031	Coshocton, OH	0.57	0	-0.88	36.15	0.77
39053	Gallia, OH	0.17	0	-0.28	0	0.17
39059	Guernsey, OH	0.68	0.07	0.37	29.18	0.88
39067	Harrison, OH	8.86	1.71	0.03	30.17	11.73
39071	Highland, OH	0.24	0	-0.12	0	0.24
39073	Hocking, OH	0.28	0	0.06	0	0.28
39075	Holmes, OH	0.36	0	0.02	1.69	0.36
39079	Jackson, OH	0.6	0.13	-1.09	55.81	0.94
39081	Jefferson, OH	0.48	0.08	-0.34	79.02	0.86
39087	Lawrence, OH	0.32	0	0.11	0	0.32
39099	Mahoning, OH	0.35	0	-0.02	0.38	0.35
39105	Meigs, OH	0.24	0	-0.5	6.98	0.25
39111	Monroe, OH	0.55	0	0.05	0	0.55
39115	Morgan, OH	0.3	0	0.04	0	0.3
39119	Muskingum, OH	0.29	0	-0.06	0	0.29
39121	Noble, OH	1.87	0	0.1	0	1.87
39127	Perry, OH	1.42	0.34	-0.04	80.14	2.56
39131	Pike, OH	0.3	0	0.08	0	0.3
39141	Ross, OH	0.17	0	-0.02	0	0.17
39145	Scioto, OH	0.17	0	-0.06	0	0.17
39155	Trumbull, OH	0.29	0	-0.12	0	0.29
39157	Tuscarawas, OH	0.94	0.16	0.27	51.28	1.43
39163	Vinton, OH	1.14	0.13	-4.27	89.74	2.17
39167	Washington, OH	0.41	0	-0.11	0	0.41

42003	Allegheny, PA	0.37	0	0.07	0.51	0.37
42005	Armstrong, PA	3.3	1.04	-0.35	60.29	5.35
42007	Beaver, PA	0.33	0	0.01	0	0.33
42009	Bedford, PA	0.58	0	0.17	3.65	0.6
42013	Blair, PA	0.39	0	-0.01	3.4	0.4
42015	Bradford, PA	0.52	0	0.44	0	0.52
42019	Butler, PA	0.52	0.03	0.17	10.03	0.57
42021	Cambria, PA	0.55	0.11	0.07	70.48	0.94
42023	Cameron, PA	0.41	0	-0.25	0	0.41
42025	Carbon, PA	0.25	0.01	0.07	22	0.31
42027	Centre, PA	0.25	0	0.11	1.41	0.25
42031	Clarion, PA	1.02	0.24	-0.03	71.79	1.76
42033	Clearfield, PA	1.18	0.33	-0.6	62.87	1.93
42035	Clinton, PA	0.33	0	0.19	0	0.33
42037	Columbia, PA	0.39	0.03	0.24	49.83	0.58
42039	Crawford, PA	0.39	0	0.13	0	0.39
42047	Elk, PA	0.44	0	-0.05	14.94	0.51
42049	Erie, PA	0.29	0	-0.06	0	0.29
42051	Fayette, PA	0.52	0.02	0.24	16.75	0.6
42053	Forest, PA	0.38	0	0.6	0	0.38
42057	Fulton, PA	1.51	0	-0.35	0	1.51
42059	Greene, PA	18.4	0	2.5	0	18.4
42061	Huntingdon, PA	0.23	0	-0.23	0	0.23
42063	Indiana, PA	1.87	0.34	0.03	35.54	2.54
42065	Jefferson, PA	1.96	0.24	0.37	94.75	3.83
42067	Juniata, PA	0.21	0	-0.02	0	0.21
42069	Lackawanna, PA	0.27	0	0	0.77	0.27
42073	Lawrence, PA	0.3	0	-0.11	0	0.3
42079	Luzerne, PA	0.48	0.03	0.03	59.15	0.76
42081	Lycoming, PA	0.49	0.02	0.36	13.87	0.56
42083	McKean, PA	0.67	0	0.29	0	0.67
42085	Mercer, PA	0.33	0	0.01	0	0.33
42087	Mifflin, PA	0.2	0	-0.12	0	0.2
42089	Monroe, PA	0.18	0	-0.06	0	0.18
42093	Montour, PA	0.25	0	-0.1	0	0.25
42097	Northumberland, PA	0.49	0.04	-0.18	100	0.97
42099	Perry, PA	0.18	0	-0.05	0	0.18
42103	Pike, PA	0.18	0	-0.03	0	0.18
42105	Potter, PA	0.37	0	-0.07	0	0.37
42107	Schuylkill, PA	1.12	0.2	0.46	100	2.24

42109	Snyder, PA	0.19	0	-0.07	0	0.19
42111	Somerset, PA	2.63	0.86	-0.39	86.22	4.93
42113	Sullivan, PA	0.33	0	0.2	0	0.33
42115	Susquehanna, PA	0.69	0	0.57	0	0.69
42117	Tioga, PA	0.41	0	0.31	0	0.41
42119	Union, PA	0.18	0	-0.02	0	0.18
42121	Venango, PA	1.59	0.02	-0.08	15.79	1.85
42123	Warren, PA	0.55	0	0.25	0	0.55
42125	Washington, PA	1.88	0	0.53	0	1.88
42127	Wayne, PA	0.31	0	0.1	0	0.31
42129	Westmoreland, PA	0.41	0.02	-0.02	5.51	0.43
42131	Wyoming, PA	0.5	0	0.61	0	0.5
45007	Anderson, SC	0.27	0	0.07	0	0.27
45021	Cherokee, SC	0.22	0	-0.06	0	0.22
45045	Greenville, SC	0.36	0	0.04	0	0.36
45073	Oconee, SC	0.33	0	-0.03	0	0.33
45077	Pickens, SC	0.2	0	-0.07	0	0.2
45083	Spartanburg, SC	0.33	0	0.06	0	0.33
47001	Anderson, TN	0.35	0	-0.09	2.54	0.36
47007	Bledsoe, TN	0.12	0	-0.06	0	0.12
47009	Blount, TN	0.29	0	0.06	0	0.29
47011	Bradley, TN	0.23	0	0	0	0.23
47013	Campbell, TN	0.41	0.06	-0.1	55.01	0.64
47015	Cannon, TN	0.39	0	0.91	0	0.39
47019	Carter, TN	0.24	0	-0.15	0	0.24
47025	Claiborne, TN	2.24	0.6	-0.76	94.57	4.38
47027	Clay, TN	0.23	0	0.01	0	0.23
47029	Cocke, TN	0.22	0	-0.1	0	0.22
47031	Coffee, TN	0.3	0	-0.03	0	0.3
47035	Cumberland, TN	0.27	0	-0.02	3.6	0.28
47041	DeKalb, TN	0.3	0	-0.11	0	0.3
47049	Fentress, TN	0.2	0	-0.03	0	0.2
47051	Franklin, TN	0.23	0	0.04	0	0.23
47057	Grainger, TN	0.23	0	-0.06	0	0.23
47059	Greene, TN	0.4	0	0.1	0	0.4
47061	Grundy, TN	0.18	0	-0.67	0	0.18
47063	Hamblen, TN	0.25	0	-0.13	0	0.25
47065	Hamilton, TN	0.34	0	-0.04	0	0.34

47067	Hancock, TN	0.07	0	-0.04	0	0.07
47073	Hawkins, TN	0.26	0	-0.33	0	0.26
47087	Jackson, TN	0.27	0	-0.14	0	0.27
47089	Jefferson, TN	0.24	0	2.13	0	0.24
47091	Johnson, TN	0.27	0	-0.15	0	0.27
47093	Knox, TN	0.33	0.01	0.06	1.84	0.33
47099	Lawrence, TN	0.27	0	-0.08	0	0.27
47101	Lewis, TN	0.26	0	-0.37	0	0.26
47105	Loudon, TN	0.3	0	-0.22	0	0.3
47107	McMinn, TN	0.33	0	0	0	0.33
47111	Macon, TN	0.19	0	-0.14	0	0.19
47115	Marion, TN	0.53	0	0.24	0	0.53
47121	Meigs, TN	0.28	0	-0.02	0	0.28
47123	Monroe, TN	0.31	0	0.15	0	0.31
47129	Morgan, TN	0.2	0	0.02	0	0.2
47133	Overton, TN	0.89	0	1.01	0	0.89
47137	Pickett, TN	0.33	0	0.15	0	0.33
47139	Polk, TN	0.16	0	0.06	0	0.16
47141	Putnam, TN	0.25	0	0.01	0	0.25
47143	Rhea, TN	0.19	0	-0.16	0	0.19
47145	Roane, TN	0.2	0	-0.08	0	0.2
47151	Scott, TN	0.35	0	-0.52	0	0.35
47153	Sequatchie, TN	0.37	0	-0.46	0	0.37
47155	Sevier, TN	0.19	0	0.76	0	0.19
47159	Smith, TN	0.44	0	4.65	0	0.44
47163	Sullivan, TN	0.27	0	0.06	0	0.27
47171	Unicoi, TN	0.39	0	-0.02	0	0.39
47173	Union, TN	0.21	0	-0.1	0	0.21
47175	Van Buren, TN	0.94	0	-0.53	0	0.94
47177	Warren, TN	0.38	0	-0.03	0	0.38
47179	Washington, TN	0.25	0	0.02	0	0.25
47185	White, TN	0.28	0	-0.12	0	0.28
51005	Alleghany, VA	0.25	0	-0.09	0	0.25
51017	Bath, VA	0.25	0	0	0	0.25
51021	Bland, VA	0.51	0	0.26	0	0.51
51023	Botetourt, VA	0.4	0	-0.19	0	0.4
51027	Buchanan, VA	15.32	4.51	-3.52	46.25	23.41
51035	Carroll, VA	0.23	0	0	0	0.23
51045	Craig, VA	0.16	0	-0.03	0	0.16
51051	Dickenson, VA	12.01	3.3	-2.86	78.21	22.1

51063	Floyd, VA	0.16	0	-0.05	0	0.16
51071	Giles, VA	0.65	0	-0.27	0	0.65
51077	Grayson, VA	0.13	0	-0.25	0	0.13
51089	Henry, VA	0.24	0	-0.04	0	0.24
51091	Highland, VA	0.35	0	-0.16	0	0.35
51105	Lee, VA	3.27	0.44	-1.05	72.7	5.68
51121	Montgomery, VA	0.32	0	0.03	0	0.32
51141	Patrick, VA	0.2	0	-0.1	0	0.2
51155	Pulaski, VA	0.25	0	-0.15	0	0.25
51163	Rockbridge, VA	0.14	0	-0.07	0	0.14
51167	Russell, VA	3.1	0.99	-1.09	54.41	4.84
51169	Scott, VA	1.38	0	0.22	0	1.38
51173	Smyth, VA	0.67	0	0.05	0	0.67
51185	Tazewell, VA	3.4	1.05	0.72	75.31	6.03
51191	Washington, VA	0.65	0	-0.8	0	0.65
51195	Wise, VA	3.89	1.1	-5.48	100	7.86
51197	Wythe, VA	0.27	0	-0.3	0	0.27
54001	Barbour, WV	4.2	1.04	2.34	88.48	7.99
54003	Berkeley, WV	0.23	0	0.02	0	0.23
54005	Boone, WV	21.87	6.54	-27.62	64.64	38.36
54007	Braxton, WV	4.24	1.18	1.37	78.23	7.64
54009	Brooke, WV	0.27	0	-0.73	0	0.27
54011	Cabell, WV	0.33	0	-0.15	0	0.33
54013	Calhoun, WV	0.6	0	-0.74	0	0.6
54015	Clay, WV	2.66	0.17	-17.44	56.24	4.16
54017	Doddridge, WV	0.88	0	1.82	0	0.88
54019	Fayette, WV	4.52	1.5	0.68	76.72	8.1
54021	Gilmer, WV	0.87	0	0.74	0	0.87
54023	Grant, WV	0.24	0.01	-4.4	100	0.48
54025	Greenbrier, WV	2.11	0.63	1.59	82.19	3.87
54027	Hampshire, WV	0.21	0	0	0	0.21
54029	Hancock, WV	0.46	0	-0.05	0	0.46
54031	Hardy, WV	0.26	0	-0.09	0	0.26
54033	Harrison, WV	0.66	0.08	-0.02	33.34	0.88
54035	Jackson, WV	0.35	0	-0.34	0	0.35
54037	Jefferson, WV	0.18	0	-0.1	0	0.18
54039	Kanawha, WV	1.52	0.44	0.02	63.28	2.49
54041	Lewis, WV	0.98	0	0.99	0	0.98

54043	Lincoln, WV	0.43	0	-1.28	43.33	0.61
54045	Logan, WV	11.57	3.51	-1.8	53	18.32
54047	McDowell, WV	14.82	3.19	-1.29	97.62	30.22
54049	Marion, WV	8.71	0.91	1.4	11.65	9.82
54051	Marshall, WV	17.31	0	4.27	0	17.31
54053	Mason, WV	0.26	0	-0.22	0	0.26
54055	Mercer, WV	1.07	0.14	0.53	69.05	1.81
54057	Mineral, WV	0.4	0.04	-0.03	28.18	0.51
54059	Mingo, WV	22.22	5.82	-5.54	50.26	35.33
54061	Monongalia, WV	0.73	0.15	0.1	49.58	1.09
54063	Monroe, WV	0.21	0	0.05	0	0.21
54065	Morgan, WV	0.17	0	-0.08	0	0.17
54067	Nicholas, WV	3.33	0.9	-2.32	84.3	6.2
54069	Ohio, WV	1.89	0	1.68	0	1.89
54071	Pendleton, WV	0.35	0	-0.05	0	0.35
54073	Pleasants, WV	0.42	0	0.11	0	0.42
54075	Pocahontas, WV	0.21	0	-0.18	0	0.21
54077	Preston, WV	0.58	0.07	-0.41	34.71	0.78
54079	Putnam, WV	0.47	0.02	0.28	8.88	0.51
54081	Raleigh, WV	5.83	2.07	0.92	82.44	10.85
54083	Randolph, WV	2.32	0.55	0.81	59.4	3.72
54085	Ritchie, WV	1.26	0	0.86	0	1.26
54087	Roane, WV	1.04	0	0.13	0	1.04
54089	Summers, WV	0.24	0	0.06	0	0.24
54091	Taylor, WV	7.63	1.1	7.73	31.32	10.13
54093	Tucker, WV	7.78	0	7.22	0	7.78
54095	Tyler, WV	0.28	0	0.23	0	0.28
54097	Upshur, WV	1.1	0.22	-0.98	86.68	2.05
54099	Wayne, WV	4.41	0.94	-1.31	100	8.91
54101	Webster, WV	13.3	2.88	0.63	69.65	23.22
54103	Wetzel, WV	0.39	0	0.39	0	0.39
54105	Wirt, WV	0.3	0	-0.25	0	0.3
54107	Wood, WV	0.22	0	-0.05	0	0.22
54109	Wyoming, WV	22.36	7.05	2.57	77.43	42.47

Data Sources: Bureau of Labor Statistics, Bureau of Economic Analysis and Mine Safety and Health Administration

Appendix III. Dependence, Impact, and Risk Formulae

Variable Definitions

The variables used in the derivations are defined as follows:

$a_{ij} \in A$	direct technical coefficients
$b_{ij} \in B = (I - A)^{-1}$	total requirements coefficients
$e_i \in E$	employment by industry
$x_i \in X$	output by industry
$\pi_i \in \pi$	industry output dollars per worker
subscript or superscript c	denotes the coal industry
subscript or superscript R	denotes a region specific variable
subscripts r, u	denote county r, county u, respectively
$\lambda_i \in \lambda$	denotes employment by industry in support of regional coal production
$x_{c,t}^{R(st)}$	total year t real output of the Appalachian regional coal industry in short tons
$x_{c,t}^{R(re)}$	total year t real output of the Appalachian regional coal industry in 2007 dollars
$p_{c,t_{2007}}$	denote the 2007 mid-year coal price
$s_i \in S$	the share of employment potentially directed to the coal industry supply chain
$s_{i,t}^{R(v)}$	denotes share s_i as the function of ARC Region variable v ($v = e$ denotes employment, $v = w$ denotes wages) in year t
$\mu_{i,r}$	similarly to shares s_i, denote county-level scores of coal dependence by industry in county r
$e_{i,r,t}$	employment by industry in county r, in year t
$w_{i,r,t}$	wages by industry in county r, in year t
$h_{i,r,t}$	number of coal-dependent jobs by industry in county r, in year t
π_r	productivity of coal industry in county r
q_r	inverse productivity index of coal industry in county r, values are between 0 (high productivity) and 1 (low productivity)
superscripts $MSHA, CEW$	denote the source of data, 'Mine Safety and Health Administration', 'Census of Employment and Wages', respectively
Λ_u	location quotient of the coal industry in county u
H_D, H_I, H_R	sets of counties with high dependence, impact, and risk scores, respectively
L_D, L_I, L_R	sets of counties with low dependence, impact, and risk scores, respectively
$C_1, \dots, C_8$	sets of counties by the eight categories

Industry CIE Scores

The objective in developing industry CIE Scores is to define, for the entire Region, the industry specific total employment requirements for the production of a specified level of regional output, λ, in this case, for the coal industry. In the absence of superior data, we assume that productivities, in terms of output per employee, are spatially invariant. Given this objective, then, and using the variables defined above, we define the following:

$$\pi_i = \frac{x_i}{e_i} \tag{1}$$

$$\pi_i^{-1} b_{ic} x_c^R = \lambda_i^R \in \lambda \tag{2}$$

Estimating coal industry output and employment

To estimate Region-wide coal industry output in 2007 dollars, we use each year's Appalachian Region coal-industry physical output (in short tons) and the 2007 mid-year coal price, yielding coal output in 2007 dollars. This ensures consistency with the 2007 national input-output table that we use for supply chain calculations. Although we no longer use national coal mining productivity, π_c, we do use the remaining elements of π, π_i $i \neq c$ (national productivity of the other sectors) in equation (2). Denote total year t real output of the Appalachian regional coal industry in 2007 dollars by $x_{c,t}^{R(re)}$. Similarly, let $x_{c,t}^{R(st)}$ be the output in short tons, and let $p_{c,t_{2007}} \left(= 45.2 \frac{USD}{st}\right)$ denote the 2007 mid-year coal price. The observed output of the years 2005 and 2015, which will be substituted into equation (2), are as follows:

$$x_{c,t_{2005}}^{R(re)} = p_{c,t_{2007}} x_{c,t_{2005}}^{R(st)} \tag{3}$$

$$x_{c,t_{2015}}^{R(re)} = p_{c,t_{2007}} x_{c,t_{2015}}^{R(st)} \tag{4}$$

In the vector of coal-supporting industry employment by industry, denoted by λ, the element of the coal industry will be replaced with $e_{c,t}^R$ the empirically observed employment of the coal industry. In the case of $i \neq c$:

$$\lambda_i^R = \pi_i^{-1} b_{ic} x_c^{R(re)} \tag{5}$$

but in the case of $i = c$:

$$\lambda_c^R = e_c^R$$

Estimating the industry CIE Scores

The variable λ now represents the industry-specific employment levels required to satisfy coal industry supply chain needs. By comparing these "sufficiency" output levels to the observed regional industrial employment levels, we can estimate the share of observed regional output by industry that is potentially supporting coal industry production. If a regional industry has less than the number employees needed to meet supply chain requirements, then the share of employment potentially directed to the coal industry supply chain, $s_i \in S$, will be 1.0, otherwise the value of s_i will be the ratio of sufficiency to observed. This is shown formally in (6), below.

$$s_i = \begin{cases} 1.0 & \lambda_i \geq e_i^R \\ \dfrac{\lambda_i}{e_i^R} & \lambda_i < e_i^R \end{cases} \tag{6}$$

Note that in this document, we rely on output to employment conversions using a fixed relationship between the two for each industry. It would be equally feasible to substitute wages for employment in these steps as a means of estimating industry supply chain sufficiency. Depending on the problem domain context, one variable might be preferred to the other on theoretical grounds.

Dependence Scores

Dependency Scores can be calculated for employment or for wages. For completeness, we provide the formulae for both in this document. For the employment-based measure, coal industry ecosystem (CIE) Dependency Scores (*CDS*) were calculated by the following formula:

$$CDS_{r,t}^{(e)} = \frac{\sum_i e_{i,r,t} s_{i,t}^{R(e)}}{\sum_i e_{i,r,t}} = \frac{\sum_i h_{i,r,t}}{\sum_i e_{i,r,t}} \tag{7}$$

Where $s_{i,t}^{R(e)}$ is the function of Appalachian Region employment $e_{i,t}^R$ whose formulation is the focus of the previous section:

$$s_{i,t}^{R(e)} = f_e\left(e_{i,t}^R\right) \tag{8}$$

The values of variable $e_{i,t}^R$ in equation (8) are the employment numbers by industry for the whole Appalachian Region, calculated as the sum of all counties' employment for each industry:

$$e_{i,t}^R = \sum_r e_{i,r,t} \tag{9}$$

Where r denotes the Appalachian Region county index

We can define $h_{i,r,t}$ as the number of coal-dependent jobs in each industry, and $H_{r,t}$ as the total coal-dependent employment in county r using the following formulas:

$$h_{i,r,t} = e_{i,r,t} s_{i,t}^{R(e)} \tag{10}$$

$$H_{r,t} = \sum_i h_{i,r,t} \tag{11}$$

The county level dependency scores can be interpreted as the weighted average of the $s_{i,t}$ industry dependency scores, where the weights are the number of employees $e_{i,r,t}$ in each industry within county r.

The derivation for Dependency Scores based on wages is similar. The wages-based index is given by:

$$CDS_{r,t}^{(w)} = \frac{\sum_i w_{i,r,t} s_{i,t}^{R(w)}}{\sum_i w_{i,r,t}} \tag{12}$$

Where $s_{i,t}^{R(w)}$ is a similar coal-supporting wages-share $w_{i,t}^{R}$ of Appalachian Region totals.

$$s_{i,t}^{R(w)} = f_w\left(w_{i,t}^{R}\right) \tag{13}$$

$$w_{i,t}^{R} = \sum_r w_{i,r,t} \tag{14}$$

For year 2005:

$$CDS_{r,t_{2005}}^{(e)} = \frac{\sum_i e_{i,r,t_{2005}} s_{i,t_{2005}}^{R(e)}}{\sum_i e_{i,r,t_{2005}}} \tag{15}$$

$$CDS_{r,t_{2005}}^{(w)} = \frac{\sum_i w_{i,r,t_{2005}} s_{i,t_{2005}}^{R(w)}}{\sum_i w_{i,r,t_{2005}}} \tag{16}$$

For year 2015:

$$CDS_{r,t_{2015}}^{(e)} = \frac{\sum_i e_{i,r,t_{2015}} s_{i,t_{2015}}^{R(e)}}{\sum_i e_{i,r,t_{2015}}} \tag{17}$$

$$CDS_{r,t_{2015}}^{(w)} = \frac{\sum_i w_{i,r,t_{2015}} s_{i,t_{2015}}^{R(w)}}{\sum_i w_{i,r,t_{2015}}} \tag{18}$$

Impact Scores

The Coal Impact Score (*CIS*) has no time index, because it was calculated using the differences between 2015 and 2005 using 2005 as the reference year. The products of the differences and the shares are summed, and then divided by the total 2005 employment. Equations (19) and (20) define the employment-based and wage-based Impact Scores.

$$CIS_r^{(e)} = \frac{\sum_i \left(e_{i,r,t_{2015}} - e_{i,r,t_{2005}}\right) s_{i,t_{2005}}^{R(e)}}{\sum_i e_{i,r,t_{2005}}} \tag{19}$$

$$CIS_r^{(w)} = \frac{\sum_i \left(w_{i,r,t_{2015}} - w_{i,r,t_{2005}}\right) s_{i,t_{2005}}^{R(w)}}{\sum_i w_{i,r,t_{2005}}} \tag{20}$$

Risk Scores

Our goal in developing a Risk Score is to develop a metric that quantifies CIE risk for employment and income loss by county. Our CIE Risk Score equation takes the following form:

$$CRS = CDS(1 + Q_r)(1 + B_r) \tag{21}$$

Where Q_r is a factor that reflects local coal mine productivity, and B_r captures local supply chain dependency in a form similar to the computation that was based on Region-wide supply-chain considerations.

Transformation of productivity into inverse productivity

A county's coal industry productivity π_r can be calculated as the ratio of that county's MSHA coal mine output to coal employment.

$$\pi_r^{MSHA} = \frac{x_{c,r}^{MSHA(st)}}{e_{c,r}^{MSHA}} \tag{22}$$

Because higher productivity coal mines imply $lower$ risk, we seek an inverse transformation of productivity data. Specifically, we denote q_r as the inverse productivity of coal mines in region r.

We derive the county measure of inverse productivity from county level productivity data using the following definition. First, we calculate the weighted average of productivity for the whole Appalachian Region:

$$\bar{\pi}^{R,MSHA} = \frac{\sum_r e_{c,r}^{MSHA} \pi_r^{MSHA}}{\sum_r e_{c,r}^{MSHA}} = \frac{\sum_r x_{c,r}^{MSHA(st)}}{\sum_r e_{c,r}^{MSHA}} \tag{23}$$

which is simply the coal output of the entire Appalachian Region divided by the corresponding coal industry total employment. Next, we calculate the weighted variance and standard deviation of productivity:

$$\sigma_{\pi}^{2} = \frac{\sum_{r} e_{c,r}^{MSHA} (\pi_{r} - \bar{\pi}^{R,MSHA})^{2}}{\sum_{r} e_{c,r}^{MSHA}} \tag{24}$$

The MSHA data present some special challenges, because there are some extremely high and low productivity data that result from output assignments to a very small number of employees. To eliminate the effect of extreme outlier data, we set the highest risk to be at and below the point of average minus the standard deviation and, similarly, the lowest risk at and above the point of average plus the standard deviation. Between the two points we define a linear transformation as seen in the following formula, so the function $f_{LT}(\,)$ is continuous, linear, and strictly decreasing between the two breakpoints; the maximum equals one, and the minimum equals zero:

$$q_{r} = f_{LT}(\pi_{r}) = \begin{cases} 1.0 & \pi_{r} \leq \bar{\pi}^{R,MSHA} - \sigma_{\pi} \\ \dfrac{\bar{\pi} + \sigma_{\pi} - \pi_{r}}{2\sigma_{\pi}} & \bar{\pi} - \sigma_{\pi} < \pi_{r} < \bar{\pi} + \sigma_{\pi} \\ 0.0 & \pi_{r} \geq \bar{\pi}^{R,MSHA} + \sigma_{\pi} \end{cases} \tag{25}$$

Local productivity-based risk

Denote by $e_{c,r}^{MSHA}$ the coal mining employment by place (MSHA data) and $e_{c,r}^{CEW}$ by residence (CEW data) in county r. Define the location quotient of the coal industry in county u using the maximum CEW and the MSHA data of employment as shown in equation (26):

$$\Lambda_{u} = \min \left[1, \frac{\max\left(\dfrac{e_{c,u}^{MSHA}}{\sum_{r} e_{c,r}^{MSHA}}, \dfrac{e_{c,u}^{CEW}}{\sum_{r} e_{c,r}^{MSHA}} \right)}{\dfrac{\sum_{i} e_{i,u}^{CEW}}{\sum_{r} \sum_{i} e_{i,r}^{CEW}}} \right] \tag{26}$$

If $e_{c,r}^{MSHA} \geq e_{c,r}^{CEW} > 0$ then:

$$Q_{r} = q_{r} \Lambda_{r} \tag{27}$$

If $0 \leq e_{c,r}^{MSHA} < e_{c,r}^{CEW}$, then we assume that the difference between the two reported values is because some of the county-resident coal miners are commuting to work in mines in neighboring counties.

Hence, we calculate the weighted average of the productivity of the neighboring counties by the following formula:

$$\pi_n = \frac{\sum_{r \in N} e_{c,r}^{MSHA} \pi_r}{\sum_{r \in N} e_{c,r}^{MSHA}} \tag{28}$$

where $r \in N$ denotes the neighbor counties. For the commuting portion of the coal employment we apply the inverse average productivity of neighbor counties obtained by the function $f_{LT}()$ defined above in (25).

$$q_n = f_{LT}(\pi_n)$$

$$Q_r = \left[\frac{e_{c,r}^{MSHA}}{e_{c,r}^{CEW}} q_r + \left(1 - \frac{e_{c,r}^{MSHA}}{e_{c,r}^{CEW}} \right) q_n \right] \Lambda_r \tag{29}$$

Risk due to localized backward linkages

Whereas the Dependence Score has been defined with respect to coal supply chain self-sufficiency at the level of the Appalachian Region, a more localized dependence metric can be developed to measure county CIE dependence on coal produced in close proximity to—within or near—each county.[8]

To implement a supply chain algorithm at the county level, we can calculate estimated coal output $\hat{x}_{c,r}$ using CEW coal employment by residence. If $e_{c,r}^{MSHA} \geq e_{c,r}^{CEW} > 0$, then the estimated output is simply the multiplication of the productivity and the number of employees by residence (CEW data):

$$\hat{x}_{c,r}^{(st)} = \pi_r^{MSHA} e_{c,r}^{CEW} \tag{30}$$

If $0 \leq e_{c,r}^{MSHA} < e_{c,r}^{CEW}$, we apply spatial productivity (i.e., the weighted average productivity of the neighbor counties) to the commuting portion of the coal industry employees:

$$\hat{x}_{c,r}^{(st)} = \pi_r^{MSHA} e_{c,r}^{MSHA} + \pi_n^{MSHA} \left(e_{c,r}^{CEW} - e_{c,r}^{MSHA} \right) \tag{31}$$

We obtain the real output in 2007 dollars using the price of coal from year 2007 so that our data remain consistent with the IO-based total requirements coefficients matrix, $b_{ij}^{US} \in B$:

$$\hat{x}_{c,r,t_{2015}}^{(re)} = p_{c,t_{2007}} \hat{x}_{c,r,t_{2015}}^{(st)} \tag{32}$$

[8] We considered using a spatially weighted production value, but chose not to introduce complexity and potential double-counting that would arise because of the spatially weighted production values contributing to the demand totals for more than one county. We did use spatial weighting for the few cases where there was no in-county coal production but substantial CIE employment.

As in the ARC level supply chain analysis, we can create variable $\lambda_{i,r}$, which represents the industry specific employment levels required to satisfy the county level coal industry needs. In the equation (33), the notation $x_{i\to c,r}$ represents the output level required in industry i to satisfy the coal industry needs.

$$\lambda_{i,r} = \frac{1}{\pi_i^{US}} b_{ic}^{US} \hat{x}_{c,r}^{(re)} = \frac{e_i^{US}}{x_i^{US}} x_{i\to c,r} = e_{i\to c,r} \tag{33}$$

In equation (33), $e_{i\to c,r}$ and $\lambda_{i,r}$ are the same thing. The notation $e_{i\to c}$ illustrates the employment level required in industry i to satisfy the coal industry needs. Again as in the computation of Appalachian Region-level shares s_i^R, we define the county level shares $\mu_{i,r}$ (Note: $\mu = 1\ if\ \lambda \geq e$):

$$\mu_{i,r} = \frac{\lambda_{i,r}}{e_{i,r}^{CEW}} = \frac{e_{i\to c,r}}{e_{i,r}^{CEW}} \tag{34}$$

Unlike the s_i^R, the industry $\mu_{i,r}$ scores are different in each county. The county level aggregated score M_r can be defined as the weighted average of these industry scores, where the weights come from CEW data excluding the coal mining sector:

$$M_r = \frac{\sum_{i\neq c} e_{i,r}^{CEW} \mu_{i,r}}{\sum_{i\neq c} e_{i,r}^{CEW}} \tag{35}$$

Finally, we can calculate the supply chain linkages factor B_r as a product of the average industry scores M_r and the inverse productivity q_r of the county. If $e_{c,r}^{MSHA} \geq e_{c,r}^{CEW} > 0$ then:

$$B_r = q_r M_r \tag{36}$$

If $0 \leq e_{c,r}^{MSHA} < e_{c,r}^{CEW}$, then we use the inverse spatial productivity (i.e., we apply the inverse transformation of the weighted average productivity of the neighbor counties). The final inverse productivity of the county is the weighted average of the inverse spatial productivity and the inverse productivity of the county itself:

$$B_r = \left[\frac{e_{c,r}^{MSHA}}{e_{c,r}^{CEW}} q_r + \left(1 - \frac{e_{c,r}^{MSHA}}{e_{c,r}^{CEW}}\right) q_n\right] M_r \tag{37}$$

Now we have Q_r and B_r factors to substitute into the original $(1 + \cdots)$ form to obtain the county level coal risk scores (CRS):

$$CRS = CDS(1 + Q_r)(1 + B_r) = CDS(1 + Q_r + B_r + Q_r B_r) \tag{38}$$

Defining categories by median

Combining the three coal scores (CDS = Coal Dependency Score, CIS = Coal Impact Score, CRS = Coal Risk Score), we can create eight categories of the counties. Denote CDS_m the median of the Coal Dependency Scores, CIS_m the median of the Coal Impact Scores, CRS_m the median of the Coal Risk Scores. The set of the counties were defined as the following:

$$H_D = \{r : CDS_r \geq CDS_m\}$$
$$H_I = \{r : CIS_r \leq CIS_m\}$$
$$H_R = \{r : CRS_r \geq CRS_m\}$$
$$L_D = \{r : CDS_r < CDS_m\}$$
$$L_I = \{r : CIS_r > CIS_m\}$$
$$L_R = \{r : CRS_r < CRS_m\}$$

The variations of the six sets above produce $(2^3 = 8)$ eight categories $C_1, \ldots, C_8$ of the counties:

$$C_1 = H_D \cap H_I \cap H_R$$
$$C_2 = H_D \cap H_I \cap L_R$$
$$C_3 = H_D \cap L_I \cap H_R$$
$$C_4 = L_D \cap H_I \cap H_R$$
$$C_5 = H_D \cap L_I \cap L_R$$
$$C_6 = L_D \cap H_I \cap L_R$$
$$C_7 = L_D \cap L_I \cap H_R$$
$$C_8 = L_D \cap L_I \cap L_R$$